EXTRACTION OF GASOLINE FROM NATURAL GAS BY ABSORPTION METHODS

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By George A. Burrell, P. M. Biddison, and G. G. Oberfell.

INTRODUCTION.

The Bureau of Mines is conducting a series of investigations, with a view to ascertaining the most efficient methods of obtaining gasoline from petroleum and natural gas. This report deals with a method of extracting gasoline from natural gas by absorbing the gasoline in oil and subsequently separating it from the oil by distillation. The process is quite different from those of compression and condensation which have been used for a number of years for extracting gasoline from casing-head natural gas, and has not heretofore been described in the literature.

MANUFACTURE OF GASOLINE FROM CASING-HEAD GAS.

The extraction of gasoline from casing-head natural gas by compression and condensation methods has become a large and lucrative industry in this country. In the year 1915 about 65,000,000[a] gallons of gasoline prepared by these methods was placed on the market. In addition, in marketing this gasoline, at many plants an equivalent quantity of naphtha was blended with the gasoline, thereby utilizing for automobile fuel and other purposes a large quantity of naphtha that otherwise would have been unsuited for these purposes. The increase for the year 1915 over 1914 was about 22,000,000 gallons. For the year 1916 the production should be more than 100,000,000 gallons. The quantity of casing-head gas treated in the year 1915 by compression and condensation methods amounted to about 24,000,000,000 cubic feet; the average yield of gasoline was 2.57 gallons per 1,000 cubic feet.[b] This casing-head gas represents natural gas that formerly went largely to waste; hence the process represented a distinct and important step in the utilization of the natural gas produced in this country.

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a Northrop, J. D., Natural gas: Press Bulletin 290, U. S. Geol. Survey, October, 1916, p. 1.
b Northrop, J. D., loc. cit.

A description of the methods employed in the manufacture of casing-head gasoline and a discussion of tests to determine whether a natural gas contains enough gasoline to warrant the installation of an extracting plant is contained in Bulletin 88[a] and Technical Paper 87.[b]

SUITABILITY OF "DRY" NATURAL GAS FOR MAKING GASOLINE.

By the compression and condensation method, only casing-head gas, or "wet" natural gas, that contains more than one gallon of gasoline per 1,000 cubic feet could be profitably treated. Hence there has been exempted from use in making gasoline not only a large amount of casing-head gas, probably more than one-half the available supply, but also the much larger amount of "dry" natural gas that is used in cities and other places for domestic, factory, and other uses. The quantity of this kind of natural gas consumed in the United States in 1914 amounted to 591,000,000,000 cubic feet.[c]

Much of this "dry" natural gas can be treated by absorption methods. The method consists essentially in bringing the natural gas in contact with an oil heavier than gasoline and letting the oil absorb the gasoline from the gas, and then separating the extracted gasoline from the oil by distillation, or in passing natural gas through naphtha, with a specific gravity of about 50° to 55°, and letting the naphtha absorb as much gasoline as desired, which increases the volume and produces a blend that is intermediate in specific gravity between natural-gas gasoline and the naphtha used.

PRODUCTION OF NATURAL GAS IN 1913 AND 1914.

The quantity and value of natural gas produced in the United States during 1913 and 1914,[d] according to figures by the United States Geological Survey, were as follows:

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a Burrell, G. A., Seibert, F. M., and Oberfell, G. G.; The condensation of gasoline from natural gas: Bull. 88, Bureau of Mines, 1915, 106 pp.

b Burrell, G. A., and Jones, G. W., Methods of testing natural gas for gasoline content, Tech. Paper 87, Bureau of Mines, 1916, 26 pp.

c Northrop, J. D., Natural gas: Mineral Resources of the United States for 1914, U. S. Geol. Survey, 1915, pt. 2, p. 753.

d Northrop, J. D., Natural gas: Mineral Resources of the United States for 1914, U. S. Geol. Survey, 1915, pt. 2, p. 751.

Quantity and value of natural gas produced in the United States in 1913 and 1914, by States.

State.	1913			1914		
	Quantity (1,000 cubic feet).	Cents per 1,000 cubic feet.	Value.	Quantity (1,000 cubic feet).	Cents per 1,000 cubic feet.	Value.
West Virginia............	245,453,985	13.92	$34,164,850	138,740,162	14.87	$35,515,329
Pennsylvania............	118,860,209	18.25	21,695,845	108,494,387	18.80	20,401,295
Ohio....................	50,612,211	20.79	10,521,930	68,270,174	21.48	14,667,790
Oklahoma................	75,017,668	9.91	7,436,389	78,167,414	10.30	8,050,039
Kansas..................	22,884,547	14.37	3,288,391	22,627,507	14.76	3,340,025
New York................	8,515,257	28.50	2,425,633	8,935,187	29.10	2,600,352
Louisiana............... }	26,652,626	7.95	2,119,948	26,774,695	8.32	2,227,999
Alabama.................						
Texas...................	12,159,755	17.05	2,073,823	13,433,639	18.38	2,469,770
California..............	11,034,597	17.07	1,883,450	17,828,928	16.33	2,910,784
Indiana.................	2,920,614	28.52	843,047	2,579,675	29.28	755,407
Illinois................	4,767,128	12.04	574,015	3,547,841	12.32	437,275
Kentucky................	1,821,526	27.99	509,846	1,421,818	34.52	490,875
Arkansas................ }	1,106,374	24.35	269,421	962,998	22.23	214,103
Colorado................						
Wyoming.................						
South Dakota............ }	66,492	46.87	31,166	60,781	44.78	27,220
North Dakota............						
Missouri................	20,865	32.57	6,795	18,085	29.41	5,319
Michigan................	1,805	77.84	1,405	2,042	70.61	1,442
Tennessee...............	2,400	25.00	600	1,200	25.00	300
Iowa....................	120	100.00	120	200	100.00	200
Total.................	581,898,239	15.10	87,846,677	591,866,733	15.90	94,115,524

The table shows a production of 591,866,733,000 cubic feet of natural gas for the year 1914, an increase of about 10,000,000,000 over the year 1913.

"DRY" NATURAL GAS AS A SOURCE OF GASOLINE.

All of this gas would not be suitable for making gasoline but most of it would be suitable. Almost all of the natural gas produced in the United States contains members of the paraffin series of hydrocarbons higher than methane. The ordinary combustion analyses of natural gas show only the two predominating paraffin hydrocarbons, which are usually methane and ethane.[a] The authors have never tested natural gas that showed methane and ethane without finding the higher paraffin hydrocarbons, such as propane, butane, pentane, and hexane—when a test was made for them. Most of the gasoline that is obtained by the absorption method comes from pentane and hexane. The so-called "ethane" gas—gas containing ethane and the higher hydrocarbons—constitutes most of the natural gas of this country. Undoubtedly more than 500,000,000,000 cubic feet of such gas is used per year. For instance, all of the natural gas used in Pittsburgh, Buffalo, Columbus, Cincinnati, Cleveland, Louisville, and hundreds of other towns contains ethane.[b] The same is true

[a] Burrell, G. A., and Seibert, F. M., The sampling and examination of mine gases and natural gas: Bull. 42, Bureau of Mines, 1913, p. 77.

[b] Burrell, G. A., and Oberfell, G. G., The composition of the natural gas used in 25 cities in the United States: Tech. Paper 109, Bureau of Mines, 1915, p. 7.

of natural gas produced in Oklahoma, Kansas, California, Texas, and other States. Some natural gas that contains methane as the only paraffin hydrocarbon is found in Louisiana, in the Caddo fields, at a few places in Oklahoma, in the Murrysville sand in Pennsylvania, and at a few other places. This natural gas is the only kind that does not carry gasoline vapors. The natural gas from a new well in which the pressure is high may not carry enough gasoline to warrant the installation of an absorption plant, but most of the natural gas produced in this country undoubtedly can be so treated. If it be assumed that 1 pint of gasoline can be obtained per 1,000 cubic feet of gas, there could be extracted 500,000,000 pints of gasoline from 500,000,000,000 cubic feet of gas, or about 60,000,000 gallons of gasoline per year. If one assumes that 2 pints per 1,000 cubic feet can be obtained the total becomes 120,000,000 gallons per year. Probably 100,000,000 gallons per year would be a conservative estimate. The authors know of one gas company that has under construction enough plants to make 20,000 gallons of gasoline per day. Some of the "dry" natural gas that the authors tested yielded 3 pints of gasoline per 1,000 cubic feet. At 20 cents per gallon the total value of the gasoline saved would be $15,000,000 per year. At 25 cents it would be about $19,000,000 per year, which is about 20 per cent of the total value of the natural gas used in 1914 and probably about $6\frac{1}{2}$ per cent of the total quantity of gasoline consumed in that year.

CONSUMPTION OF GASOLINE.

During the year 1909 the quantity of gasoline consumed in the United States amounted to about 11,000,000 barrels of 42 gallons each; in 1914 the consumption had increased to 30,000,000 barrels, and it is estimated that the consumption in 1916 will be more than 50,000,000 barrels, or more than 2,100,000,000 gallons.

TRANSPORTATION OF NATURAL GAS.

After a gas well has been cased and "shut in" by closing the gate valves on the top of the tubing the well is under control, and the product is ready to be piped to market. Sometimes the rock pressure in a new field is very high, ranging from 600 to 1,000 pounds to the square inch, and it is necessary to reduce the pressure at the well so the gas can be safely turned into the pipe line. This is accomplished by means of reducers that automatically regulate the pressure. In fields that have been drained to such an extent that the rock pressure is very low the pressure in the lines has to be increased. By increasing the pressure, say, to 300 pounds the carrying capacity of a gas line is 21 times greater than at atmospheric pressure. Therefore, it is necessary to build compressing stations, because without them the size and number of mains that would be required to transport the gas from the wells to market would be so large as to make investment impracticable.

As the gas leaves the compressing station it is very hot from being compressed, so that the trunk lines for a short distance from the station are either laid in the bed of a convenient stream or run through a reservoir in order to cool the gas, which is necessary because high temperature reduces the line capacity and has a detrimental effect on coupling rubbers.

The next stopping point for the gas is the measuring and regulating station at the edge of the town, where the pressure is reduced to, say, 50 pounds; it then passes through a medium pressure regulator where it is reduced to 15 to 20 pounds; and a low pressure regulator where it is reduced to 4 to 6 ounces.

EFFECT OF GASOLINE VAPORS ON PIPE-LINE COUPLINGS.

After the gas leaves the compressing station, its capacity for holding gasoline vapors is less because it is compressed, and considerable gasoline is deposited at the cooling station and at various places along the pipe line. The condensation of gasoline in the trunk lines is a constant source of annoyance and expense, because of the action of gasoline on the rubber rings in the patent pipe couplings, which are now universally used on all large pipe lines in place of the old style socket-and-thread "collars." The gasoline softens and decomposes the rubber until it weakens and gives way, causing a "blow-out;" that is, the pipe line will part and let gas escape.

Repairing "blow-outs" is a large item of expense, apart from the large quantities of gas lost. The expense and annoyance from the breaking of a gas line and escape of gas are shown by the recent experience of a large pipe-line company. A report was received at the main office that the pressure on a certain line was falling at the rate of 30 pounds per square inch per hour, although the compressing station reported that the pressure was normal there. Men were immediately dispatched to patrol the line, and discover the leak, which was found about midnight. Twenty-six men worked the rest of the night and the next day in order to repair the line. During this time the pressure had to be raised 70 pounds at the compressing station, and the factory service on the line had to be discontinued.

One company informed the authors that the cost of rubber for couplings used in an 18-inch pipe line 35 miles long, which has transported 100,000,000,000 cubic feet in 10 years, was $16,000. This did not include the cost of placing the couplings or other expense.

Thus it seems that a method for removing the gasoline from natural gas would prolong the life of the couplings, in addition to the fact that a valuable fuel is recovered.

DEVELOPMENT OF THE ABSORPTION PROCESS.

As in the case of condensation and compression methods, the absorption process has assumed industrial importance as the demand for gasoline has increased. The process closely resembles the process

of extracting benzol, toluol, and other products from gas made by the destructive distillation of coal.   In the absorption process the gas is caused to flow at about atmospheric pressure countercurrent to a stream of wash oil, which is a petroleum distillate of about 35° Beaumé gravity or a coal-tar distillate such as creosote oil, through absorbing towers 50 to 75 feet high and about 10 to 15 feet in diameter.   After the benzol and toluol have been scrubbed from the gas, the charged oil is sent to steam stills where the benzol and toluol are extracted. The process is continuous in that the absorbent oil is used over and over again.   The scrubbing process has been used for many years in Germany and to a very large extent in the United States in connection with gas-manufacturing plants and by-products coke plants.   Many types of absorbers and steam stills, and different conditions of temperature and pressure were employed before a standard procedure was evolved.   The difference between the process of extracting gasoline from natural gas at high pressures and that of extracting benzol and toluol from coke-oven gases is that the absorption of gasoline is conducted at these high pressures, as it is necessary not to disturb the pressure in the pipe-line system.

There might also be mentioned a process in vogue for a number of years past, and practiced at some refineries, of subjecting uncondensed gas and petroleum vapors from stills to absorption in naphtha, thereby increasing the gasoline yield considerably.

Von Groeling's patent [a] covers a process for "Improvements in or relating to the utilization of natural gases or petroleum distillation gases."   The claims follow:

(1) A process for the utilization of natural gases or of petroleum distillation gases, consisting in treating the gases at an adjustably increased pressure and adjustably reduced temperature, by quantities determined beforehand, of an absorption medium, for instance of heavy benzine, the unabsorbed gases being then condensed by the use of high pressure and low temperature.

(2) An apparatus for use in carrying out the process set forth in claim 1, in which the gas is treated, in a series of absorption apparatus arranged one behind another, at an adjustably varying increased pressure and adjustably varying reduced temperature, with the absorption medium, so that said absorption medium can circulate through the various absorbers, and the heat absorbed during the expansion of the compressed gases is withdrawn directly from the absorption medium for the purpose of cooling the latter.

(3) A process of the kind set forth in claim 1, in which the gases utilized are first washed at an ordinary temperature and normal pressure with "heavy benzine."

(4) A process of the kind set forth in claim 1, in which the natural gases escaping from a bore hole, or petroleum distillation gases are first heavily compressed, then cooled and finally washed, in the state of exceedingly fine division, with cooled liquid benzine or the like, for the purpose of separating portions of the gas that can be condensed, both the cooling of the benzine required for the washing and the cooling of the gas utilized after the compression being effected with the expanding

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a Von Groeling, Albrecht, English Patent 30229, issued Dec. 24, 1909.

gases escaping from the absorption column, the gas being finally condensed by the use of high pressure and low temperature.

(5) An apparatus for use in carrying out the process set forth in claims 1, or 4, comprising a column several meters high filled with benzine or the like, into the bottom portion of which the compressed cooled natural gases enter in a state of exceedingly fine division, the upper portion of the column being provided with an expansion valve through which the washed expanded gases pass downwards through an expansion coil or the like, through the washing liquid, for the purpose of cooling the same, and then proceed to the cooling.

(6) A process of the kind set forth in claim 1 for utilizing natural gases or petroleum distillation gases by fractional condensation or absorption, in which the absorption medium is obtained by the preliminary condensation of the gas to be utilized, which is submitted to the gases still noncondensed, the cooling required for the condensation or absorption being obtained by the expansion of compressed gases or by evaporation of already condensed products under a relieved pressure, the gas being finally condensed by the use of high pressure and low temperature.

Saybolt's patent [a] specifies:

(1) That natural gas of the kind supplied to cities be subjected at pressures not less than 30 pounds per square inch to a naphtha-absorbing menstruum and by the aid of the same under high pressure, effecting the separation in industrial quantity from said gas of a natural gas naphtha, liquid at atmospheric pressure and temperature, and applicable to the uses of petroleum naphtha of similar volatility, substantially as described.

(2) The process of obtaining naphtha from combustible gas of natural origin and underground source of the kind supplied by means of wells and pipe lines to the cities for consumption therein, which process consists in subjecting such gas in the requisite large amount on the way from its underground sources to its places of consumption and under a high pressure, not less than 30 pounds per square inch above atmospheric pressure, to a naphtha-absorbing menstruum, especially petroleum or hydrocarbon oil as specified, and by the aid of the same under said high pressure effecting the separation in industrial quantity from said gas, of a natural gas naphtha liquid at atmospheric pressure and temperature and applicable to the uses of petroleum naphtha of similar volatility, and then recovering the naphtha in liquid form from said menstruum by distillation under a low pressure, not more than about atmospheric pressure, substantially as described.

(3) The process of obtaining naphtha from combustible gas of natural origin and underground source of the kind supplied by means of wells and pipe lines to cities for consumption therein, which process consists in subjecting such gas in the requisite large amount on the way from its underground sources to its places of consumption and under a high pressure, not less than about 30 pounds per square inch above atmospheric pressure, to a naphtha absorbing menstruum by causing the gas to bubble up through pools of the menstruum, and by the aid of the same under said high pressure effecting the separation in industrial quantity from said gas of a natural gas naphtha liquid at atmospheric temperature and applicable to the uses of petroleum naphtha of similar volatility, substantially as described.

Hastings and Brink's patent [b] covers an apparatus for removing gasoline from gas under compression, consisting of a reservoir constructed to contain a cooling fluid, a number of headers arranged in the reservoir, cooling pipes connecting the headers, expansion cham-

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[a] Saybolt, G. M., U. S. Patent No. 989927, issued Apr. 18, 1911.

[b] Hastings, D., and Brink, A. W., U. S. Patent 867,505, applied for Dec. 10, 1906, issued Oct. 1, 1907.

bers placed in the pipes and of greater diameter than the pipes, means for discharging the liquid condensed in these chambers, and water-spraying tubes, arranged centrally around the pipes, provided with perforations for directing jets of water transversely across the pipes in the path of the stream of gas. The inventors also claim the use of oil instead of water as the separating medium.

Snee's patent [a] specifies a means of providing for the retention of lighter or more volatile oils contained in the product of oil wells, gas wells, and gas wells that produce both oil and gas. The claims follow:

(1) The method herein described consisting in discharging all of the liquid and gaseous hydrocarbon products of an oil well into a liquid and gas container, and absorbing the gaseous hydrocarbons which accumulate within the container above the surface of the liquid.

(2) The method herein described consisting in discharging all of the liquid and gaseous hydrocarbon products of an oil well into a liquid and gas container beneath the fluid level of the latter, and removing and absorbing the gaseous hydrocarbons released from the liquid within the container.

(3) The method herein described consisting in discharging all of the oil from an oil well into an oil and gas container, passing the gaseous products of the well into the oil thus discharged beneath the surface of the latter, and removing and absorbing the gaseous products released from the surface of the oil.

In Koppers' process [b] for extracting naphtha from natural gas the latter is passed under pressure through a solvent oil in a cast-iron bell washer, which is relieved of pressure by placing it within a wrought-iron casing through which gas passes.

To the authors' knowledge, the first large-scale plant for extracting gasoline from natural gas by the absorption method was built at Hastings, W. Va., after extensive experiments by G. M. Saybolt, of the operating company. The plant began operations in 1913. The process consists in causing the natural gas to bubble up through a petroleum distillate of about 35° B. gravity at high pressure, which is then sent to a steam still to separate the gasoline, and is used over and over again. The gas is passed through the absorbing oil at the high pressure of the line. The hot oil from the stills is cooled in a double-pipe cooler or exchanger by the cold oil en route to the still and is further cooled by passing through pipes on which running water falls. The general process, except for the utilization of the gas under high pressure, is identical with the process of absorbing benzol and toluol vapors from coke-oven gases, which has been used for years in Germany and to a large extent during 1915 in the United States.[c]

a Snee, John, U. S. Patent 1165458, issued Dec. 28, 1915.

b Koppers, H., U. S. Patent 1107803, issued Aug. 18, 1914.

c A patent granted to William Young, of Clippens, Renfrewshire, England, on Sept. 7, 1875, describes (Redwood, J. I., Mineral oils and their by-products, 1914, p. 303) a tower with an upper compartment filled with coke to act as a distributing medium. Oil, descending through the coke, mixes with gas traveling upward, and absorbs hydrocarbon vapors. Then, saturated with absorbed hydrocarbon vapors, the oil passes into the lower part of the tower comprising a still, where live or exhaust steam distills off the absorbed vapors. The patentee states that the gases and heavy oils may be brought in contact under pressure. This process, described by Young 42 years ago and covering all hydrocarbon vapors, is identical with the absorption process for natural gas to-day.

OCCURRENCE OF GASOLINE IN NATURAL GAS.

When gas bubbles through or comes in contact with a liquid, it takes up and carries along vapor or minute particles of that liquid. The proportion of vapor that the gas can hold increases as the temperature rises, and is quite independent of the nature of the gas as long as no chemical action takes place. When natural gas in the earth comes in contact with petroleum, those fractions of the petroleum having the lower boiling points will be taken up first, as their vapor pressures are much higher than those of the other fractions. The vapors are carried with the gas in the same manner that water vapor exists with air. The amount of water vapor present in air is principally dependent upon the temperature of the air and the readiness with which the air can obtain the water. If the temperature of air saturated with water vapor be lowered, water vapor will deposit from the air, for air can hold only a certain quantity of water vapor at a particular temperature. Also, if a mixture of air and water vapor that is at a temperature below the critical temperature of water vapor is subjected to pressure, more water vapor can be condensed from the mixture by increasing the pressure. Also, if air containing water vapor be passed through a liquid that absorbs water vapor, it will be removed from the air.

These statements hold true for natural gas that contains gasoline vapor. The gasoline can be removed by compression and condensation, as in the manufacture of casing-head gasoline, or by passing the natural gas through an oil that absorbs gasoline, as in the absorption method.

COMPARISON OF "WET" AND "DRY" NATURAL GAS.

Natural gas is essentially a mixture of gases in which the paraffin series of hydrocarbons predominate, with much smaller proportions of carbon dioxide and nitrogen. Some natural gas contains small amounts of hydrogen sulphide.

"Wet" natural gas contains the higher members of the paraffin series of hydrocarbons in much larger quantity than "dry" natural gas, as is shown by the table following.

It will be observed that there is considerable difference between the two analyses. The "wet" gas, or casing-head gas, represents natural gas that is used for the extraction of gasoline by compression methods; the "dry" gas is typical of several hundred billion cubic feet of natural gas that is used each year in the United States for domestic and industrial uses and from which gasoline can be extracted by the absorption method.

Methane, ethane, propane, and butane are gases at ordinary temperatures. Pentane and hexane are liquids at ordinary temperatures, and are those vapors carried by the gases that constitute most of the gasoline extracted from natural gas. Some butane and, in casing-head

gasoline plants, some propane are also extracted and are chiefly responsible for the "wildness" or high vapor pressure of some gasoline extracted from natural gas by compression and condensation methods.

Casing-head gas represents gas that occurs in contact with oil and hence has an excellent chance to mingle with and carry out of the well some of the lighter vapors—the gasoline of the oil. Furthermore, such natural gas is usually under low pressure. In fact, many oil wells are operated under a vacuum, so that most of the gas has been removed in the past and that being withdrawn consists largely of gasoline vapors. The greater the content of gasoline in the oil and the greater the partial vacuum applied to the well the more gasoline vapor, other things being equal, will be withdrawn from the well.

Results of fractionation analyses of "wet" and "dry" natural gas.a

Constituent.	"Dry" gas.b	"Wet" gas.
	Per cent.	*Per cent.*
Methane......................	84.7	36.8
Ethane.....	9.4	32.6
Propane	3.0	21.1
Butane	c1.3	5.8
Pentane, hexane, etc........	....	3.7
Carbon dioxide.............	Trace.	Trace.
Nitrogen...................	1.6	(d)
	100.0	100.0

The "dry" gas, on the other hand, is under pressure ranging from a few pounds to 1,000 pounds per square inch, depending on the well from which it flows. It represents gas that once was in contact with oil or was formed by the same processes that produced the oil. In many cases it represents an escape of lighter hydrocarbons from a sand that contains both oil and gas. Hence the gas carries with it some of the lighter liquid hydrocarbons, or gasoline vapors. In some sands where the gas is under high pressure, however, the gasoline vapors may remain in the gas sand, because of their greater density at that pressure, and only to a slight extent issue with the gas, until the pressure has been relieved to a certain extent. Hence the pressure in a "dry gas" well is one of the factors that determine the gasoline content of the gas. It is possible, however, that even in the case of "dry" natural gas that does not carry enough gasoline to warrant its use in an absorption process such gas may represent a potential gasoline supply that can be obtained when the pressure on the well has been relieved.

a Burrell, G. A., Seibert, F. M., and Robertson, I. W., The analysis of natural gas and illuminating gas by fractional distillation at low temperatures and pressures: Tech. Paper 104, Bureau of Mines, 1915, pp. 16, 19.

b Combustion analysis showed 79.2 per cent methane, 19.6 per cent ethane, trace of carbon dioxide, and 1.2 per cent nitrogen.

c Chiefly butane, includes pentane and hexane.

d About 1 per cent.

METHODS OF TESTING NATURAL GAS FOR ITS GASOLINE CONTENT.

Methods in use by the Bureau of Mines for testing natural gas have been described in Bulletin 42[a] and Bulletin 88.[b]

For the purposes required the tests given are satisfactory; but, in order to test natural gas with a view to using it in the absorption process, tests of a different nature had to be devised, because of the small gasoline content in "dry" natural gas. The tests embrace a method that is essentially a laboratory method and another test that can be made in the field by persons who are not chemists.

LABORATORY METHOD.

The method for use in laboratories may be called a freezing method; that is, the gasoline is condensed out of the natural gas and the yield measured. The principle of this method, which has been described in Technical Paper 104,[c] is as follows:

The apparatus shown in figure 1 is exhausted of its air, and the sample of natural gas to be tested is introduced at atmospheric pressure. Next the bulb b is surrounded with gasoline that has been cooled to a temperature of about $-115°$ C. by means of liquid air. After the gas has been cooled about 10 minutes, and with the refrigerant still surrounding the bulb, as much gas as possible is removed with a vacuum pump. Next the refrigerant is removed and the gas in the bulb allowed to rise to its original temperature—that is, room temperature. The liquefied gasoline will vaporize and exert pressure on the mercury in the manometer. If the atmos-
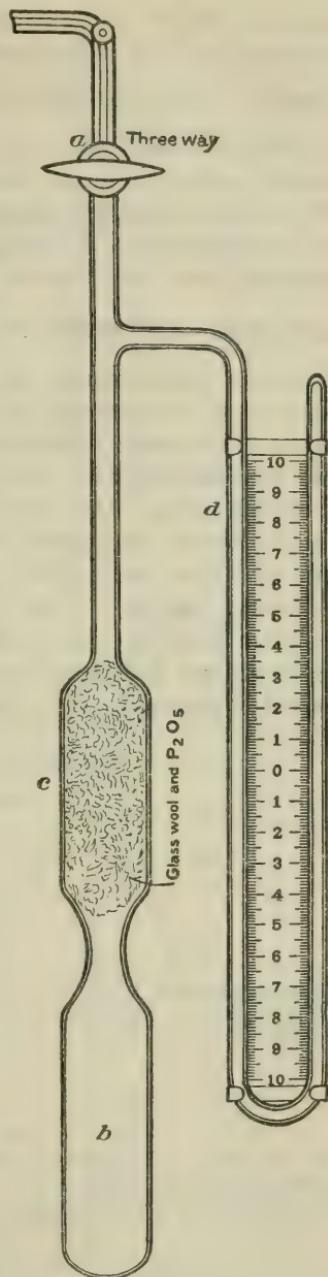
FIGURE 1.—Apparatus for determining gasoline vapor in natural gas.

[a] Burrell, G. A., and Seibert, F. M., The sampling and examination of mine gases and natural gas: Bull. 42, Bureau of Mines, 1913, 116 pp.

[b] Burrell, G. A., Seibert, F. M., and Oberfell, G. G., The condensation of gasoline from natural gas: Bull. 88, Bureau of Mines, 1915, 106 pp.

[c] Burrell, G. A., Seibert, F. M., and Robertson, I. W., Analysis of natural gas and illuminating gas by fractional distillation at low temperatures and pressures: Tech. Paper 104, Bureau of Mines, 1915, p. 26.

pheric pressure—the pressure of the original sample—is 740 mm. of mercury and the partial pressure of the gasoline vapor is 10 mm. of mercury, then the content of gasoline vapor in the sample is $\frac{10}{740}$ × 100 =1.4 per cent. The authors found that this figure corresponds, in pints of gasoline per 1,000 cubic feet of gas, with the amount of gasoline actually obtained in plant practice. This vapor liquefied and held at −115° C. represents[a] practically all of the gasoline constituents, and also the butane.

ANALYSES AND TESTS OF NATURAL GAS USED IN EXPERIMENTS.

At the plant where the authors conducted their tests with the absorption process natural gas from two different fields was available. The results of laboratory tests that the authors made of this gas to determine its composition and properties are given in the table following. Determinations were made on gas that had not been treated by the absorption process, and also on gas from which the gasoline had been removed by passing it through absorbers containing "mineral seal oil." The gas designated as "line L" gas is from wells in Ashland County, Ohio, and the "low field" gas is from wells in Knox and Licking Counties, Ohio; these terms are local and are used for convenience in designating the two sources of gas used.

Results of tests of fresh and treated natural gas.

COMBUSTION ANALYSIS.

	Fresh natural gas.		Treated natural gas.	
	"Low field" gas.	"Line L" gas.	"Low field" gas.	"Line L" gas.
Carbon dioxide (CO₂)..............................per cent..	Trace.	Trace.	Trace.	Trace.
Methane (CH₄)...do....	76.3	83.9	79.7	88.3
Ethane (C₂H₆)..do....	18.4	11.7	14.1	7.9
Nitrogen (N₂)..do....	5.3	4.4	6.2	3.8
	100.0	100.0	100.0	100.0

PHYSICAL PROPERTIES.

Specific gravity..	0.68	0.63	0.65	0.61
Absorption in Russian white oil[b]................	17.0	15.0	16.7	14.0
Gross heating value, B. t. u. per cubic foot at 0° C. and 760 mm. pressure..............	1,155	1,111	1,111	1,087

GASOLINE CONTENT BY FREEZING METHOD.

Gasoline (butane, pentane, hexane, etc.). pints, per 1,000 cubic feet	1.3	0.8	....	....

[a] See Burrell, G. A., and Jones, G. W., Methods of testing natural gas for gasoline content: Tech. Paper 87, pp. 12–14, Bureau of Mines, 1916.
[b] For method of using see absorption by claroline, as described by Burrell, G. A., and Jones, G. W., Methods of testing natural gas for gasoline content; Tech. Paper 87, Bureau of Mines, 1916, pp. 7–10.

COMMENTS ON ANALYSES.

The difference in the natural gas before and after the gasoline has been extracted is interesting. The heating value of the "low field" gas was lowered 44 B. t. u. or 3.8 per cent, the specific gravity dropped from 0.68 to 0.65, and the proportions of paraffin hydrocarbons calculated as methane and ethane were altered. The heating value of "line L" gas was lowered 24 B. t. u., or 2.2 per cent, and the specific gravity dropped from 0.63 to 0.61.

INFERENCE TO BE DRAWN FROM COMBUSTION DATA.

The results in an ordinary combustion analysis of natural gas show only the two predominating paraffin hydrocarbons, usually the methane and ethane. The presence of ethane signifies the presence of higher paraffin hydrocarbons, including gasoline vapors; and it is probable that most natural gas that contains ethane contains enough gasoline to be treated by the absorption process, with the exception, perhaps, of natural gas from new wells under high pressure, and these wells may be potential sources of gasoline that will be produced when the pressure drops sufficiently low.

TESTS WITH SMALL PORTABLE ABSORBER.

A number of tests on a small scale were made with the small

FIGURE 2.—Small absorber for testing natural gas for gasoline content.

absorber shown in figure 2. The absorber, which is built on the principle of a laboratory gas-washing bottle of the Friedrick type, was made of iron pipe and thoroughly welded. It is about 3 feet high, and the two main barrels a and b were made of 4-inch pipe. The

entering gas bubbles up through the absorbing oil at c and passes through the coil of pipe f and into the part d and out at e. This apparatus was designed as a very efficient absorber, to show the maximum possible yield of gasoline from natural gas.

In passing natural gas with its gasoline vapor through an absorbent oil, there will occur a point in the solution process when a particular oil will not take up any more gasoline. In tests by the authors with "mineral seal oil" the saturation point of this oil was determined to be 28 per cent. In conducting the tests natural gas was passed through the oil, using the small absorber shown in the figure, until no more gasoline was absorbed by the oil. By a saturation of 28 per cent is meant that the gasoline content was 28 per cent of the total volume of gasoline and oil.

In practice, however, the percentage of the gasoline absorbed in the oil should not be carried that far. Tests showed that when the absorption of gasoline exceeded 4 per cent, some of the gasoline in the natural gas passing through the oil was not extracted and passed out with the gas. As the percentage was increased and more gasoline was absorbed, an increasingly small amount appeared in the exit gases, which was always less than the amount absorbed until the saturation point, 28 per cent, was reached, when the percentage in the entering gas was equal to the percentage in the gas given off, that is, no more gasoline was being absorbed.

Therefore in all tests made both on the small absorbers and on the larger experimental plants, a close watch was kept on the percentage of the gasoline in the absorbent. This can be regulated by adjusting the feed of gas and the amount of oil used.

OILS USED IN TESTS.

Two different oils were used as the absorbing medium in these tests. One of them was the "mineral seal oil" used in the previous tests, the other, known as "straw oil," was also a petroleum distillate. Their characteristics as determined by E. W. Dean, petroleum chemist of the Bureau of Mines, were as follows:

Characteristics of oils used as absorbents.

"MINERAL SEAL OIL."

Flash point (Pensky-Martin closed apparatus)......... 135° C., 275° F.
Burning point (Pensky-Martin open apparatus)....... 160° C., 320° F.
Specific gravity (Water=1)..................................... 0. 850

First drop distilled at 225° C. (437° F.); 6.2 per cent was distilled on heating to 275° C. (527° F.).

"STRAW OIL."

Flash point (Pensky-Martin closed apparatus)......... 183° C., 361° F.
Burning point (Pensky-Martin open apparatus)....... 208° C., 406° F.
Specific gravity (Water=1)..................................... 0. 851

First drop distilled at 250° C. (482° F.); vapor began to distill in quantity at 275° C. (527° F.).

RESULTS OF TESTS OF NATURAL GAS WITH SMALL ABSORBER.

The results of tests of "low field" and "line L" natural gas with "mineral seal" oil and absorbers of the type shown in figure 2 are given in Table 1. Three of these absorbers, designated as Nos. 1, 2, and 3 in Table 1, were connected in series. The natural gas passed through absorbers 1, 2, and 3, in the order mentioned, then through a small domestic gas meter where the gas flow was measured. The gas was passed through the oil under a pressure of 235 pounds per square inch. Other data given in the table are: (1) Rate of flow of gas per hour; (2) cubic centimeters of oil used; (3) cubic feet of gas used; (4) temperature of oil; (5) cubic centimeters of oil and gasoline recovered; (6) absorption of gasoline in the oil, per cent; (7) amount of sample taken from absorber at end of test in order to make a distillation test; (8) amount of gasoline obtained from oil sample by distillation; (9) amount of gasoline from oil sample, calculated to represent all the gasoline in the oil; (10) boiling points of the extracted gasoline; (11) cubic centimeters of oil used in the test per 1,000 cubic feet of gas; (12) pints of gasoline obtained in each absorber for each 1,000 cubic feet of gas used; (13) gravity of the extracted gasoline, degrees Baumé; (14) total amount of gasoline obtained from the three absorbers.

The reader should note that in this report the terms "gravity" and "specific gravity" are both applied to degrees Baumé, although strictly speaking neither application is correct. Oil men generally use the term "gravity," but the Baumé scale is a hydrometric scale and measures the density of a liquid.

TABLE 1.—*Results of gasoline extraction tests*

[Pressure in absorber, 235

"MINERAL SEAL OIL

Item.	"Low field" gas.								
	Test 1.			Test 2.			Test 3.		
Date of test	Jan. 10, 1916.			Jan. 10, 1916.			Jan. 12, 1916.		
Number of absorber	1	2	3	1	2	3	1	2	3
Rate of flow of gas, cubic feet per hour	360	360	360	240	240	240	190	190	190
Oil used, c. c.	1,750	1,500	1,500	1,750	1,500	1,500	1,750	1,500	1,500
Gas used, cubic feet	202	202	200	200	200	200	200	200	200
Temperature of oil, ° F	58	60	62	60	60	64	70	73	73
Oil and gasoline recovered, c.c.	1,950	1,580	1,550	1,980	1,600	1,570	1,990	1,600	1,570
Absorption of gasoline, per cent a	7.9	2.3	.4	7.0	2.1	.2	6.9	1.4	.04
Sample taken for distillation test, c. c.	650	527	517	660	533	523	663	533	523
Gasoline obtained from sample by distillation, c. c.	45	12	2	46	11	1	45.5	7.5	.2
Total gasoline recovered in test, c. c. a	135	36	6	138	33	3.0	136.5	.6	......
Oil used per 1,000 cubic feet of gas, c. c.	8,750	7,500	7,500	8.750	7,500	7.500	8,750	7,500	7,500
Gasoline from each absorber, pints per 1,000 cubic feet of gas	1.42	.36	.06	1.46	.35	.03	1.44	.24	.01
Specific gravity of gasoline, ° B	84	.....	.....	84	.....	.....	85	.....	.....
Boiling point of gasoline, ° F	110–250	150–250	150–250	110–250	145–250	150–250	130–250	145–250	......
Total gasoline from three absorbers, pints per 1,000 cubic feet of gas	1.84			1.84			1.69		

"STRAW OIL" USED

Item.	"Low field" gas.					
	Test 11.			Test 12.		
Date of test	Jan. 10, 1916.			Jan. 12, 1916.		
Number of absorber	1	2	3	1	2	3
Rate of flow of gas, cubic feet per hour	106	106	106	100	100	100
Oil used, c. c.	1,750	1,500	1,500	1,750	1,500	1,500
Gas used, cubic feet	100	100	100	200	200	200
Temperature of oil, ° F	63	64	64	68	68	68
Oil and gasoline recovered, c. c.	1,890	1,540	1,515	1,905	1,570	1,550
Absorption of gasoline, per cent	3.7	.2	0	5.8	1.1	.5
Sample taken for distillation test, c. c.	630	513	503	635	523	310
Gasoline obtained from sample by distillation, c. c.	23	1.0	0	37	6	1.5
Total gasoline recovered, c. c.	69	3	......	111	18	7.5
Boiling point of gasoline, ° F	114–290	172–250	......	110–280	120–270	136–260
Specific gravity of gasoline, ° B	......	......	......	85.7	......	......
Gasoline from each absorber, pints per 1,000 cubic feet of gas	1.46	.06	......	1.17	.19	.08
Total gasoline from three absorbers, pints per 1,900 cubic feet of gas	1.52			1.44		

a Calculated on total quantity of oil and gasoline.

of natural gas with small absorption plant.

pounds per square inch.]

USED AS ABSORBENT.

"Low field" gas—Continued.												"Line L" gas.			
Test 4.			Test 5.			Test 6.			Test 7.			Test 8.		Test 9.	Test 10.
Jan. 12, 1916.			Jan. 12, 1916.			Jan. 4, 1916.			Jan. 4, 1916.			Jan. 1, 1916.		Jan. 1, 1916.	Jan. 1, 1916.
1	2	3	1	2	3	1	2	3	1	2	3	1	2	2	1
190	190	190	50	50	50	89	89	89	159	159	159	88	88	94	91
1,750	1,500	1,750	1,750	1,500	1,500	1,750	1,500	1,500	1,750	1,500	1,500	1,750	1,500	1,500	1,500
100	100	100	200	200	200	200	200	200	200	200	200	50	50	100	100
65	66	66	66	68	68	57	57	58	57	58	58	50	49	53	50
1,870	1,545	1,535	1,945	1,555	1,555	2,025	1,650	1,650	2,000	1,600	1,570	1,865	1,540	1,590	1,610
3.9	.8	.04	7.3	1.6	.4	7.2	2.2	.2	8.1	2.4	.6	1.8	0	3.6	3.4
623	515	512	648	518	518	506	550	780	500	533	785	622	770	795	537
24	4	.2	47.5	8.5	2.0	36.5	12.0	1.7	40.5	12.8	5.0	11.0	0	28.2	18
72	12	.6	142.5	25.5	6	146	36	34	162	38.4	10	33	0	56.4	54
17,500	15,000	15,000	8,750	7,500	7,500	8,750	7,500	7,500	8,750	7,500	7,500	35,000	30,000	15,000	15,000
1.52	.25	......	1.50	.27	.06	1.54	.38	.04	1.71	.41	.11	1.40	0	1.19	1.14
						83.7			×4						
{ 130–250	145–250 }	......	{ 110–250	125–250 }	......	{ 110–260	110–254	100–250	116–250	116–250	106–250	125–240 }	......	{ 130–270	130–260
1.78			1.84			1.96			2.23			1.40		1.19	1.14

AS ABSORBENT.

"Low field" gas—Continued.			"Line L" gas.								
Test 13.			Test 14.			Test 15.			Test 16.		
Jan. 20, 1916.			Jan. 19, 1916.			Jan. 19, 1916.			Jan. 20, 1916.		
1	2	3	1	2	3	1	2	3	1	2	3
106	106	106	200	200	200	195	195	195	55	55	55
1,750	1,500	1,500	1,750	1,500	1,500	1,750	1,500	1,500	1,750	1,500	1,500
400	400	400	400	400	400	400	400	400	200	200	200
62	63	63	60	60	60	55	52	50	68	70	70
1,995	1,615	1,540	1,925	1,540	1,550	1,860	1,620	1,560	1,850	1,570	1,540
9.4	3.9	1.6	5.5	3.9	1.1	6.5	3.1	1.3	4.2	1.1	.1
658	538	308	642	513	517	620	540	520	617	523	•513
62	21	4.8	35.5	20	5.9	40.5	16.5	7.0	26	6	.5
186	63	24	107	60	17.7	121.5	49.5	21.0	78	18	1.5
96–340	130–300	144–290	94–290	110–280	165–275	113–300	130–295	160–290	118–290	130–275	210–260
83.1	....	....	.54	.32	.09	.64	.26	.11	.82	.18	.02
.98	.33	.13	79.3	....	....	80.8	....	....	83.5	....	....
1.44			0.95			1.01			1.02		

COMMENT ON RESULTS OF TESTS.

After each test was finished, a small sample (about 500 c. c.) of the oil was distilled and the yield of gasoline measured. The total quantity of gasoline in the oil was calculated from the quantity obtained from this small sample. The yield in pints of gasoline per 1,000 cubic feet of gas was calculated from this data and from the amount of natural gas used in the test. In general, when the percentage of gasoline absorbed in the oil was high in the first absorber, it was high in the second one.

Tests 1 to 7, with "low field" gas, show that in the small absorbers used a yield of gasoline varying from 1.77 pints to 2.23 pints per 1,000 cubic feet of gas could be obtained. Most of the gasoline was extracted in the first absorber, and the rest in the second, practically no gasoline being obtained in the third. In other words absorption was practically complete with two absorbers. The absorption percentage, 7 to 8 per cent, was allowed to rise too high in the first absorber to extract all the gasoline in one absorber.

The yield of gasoline from the "line L" gas, tests 8 to 10, was less than from the "low field" gas. In test 8 two absorbers were used in series but for tests 9 and 10 only one absorber was used. The absorption of gasoline was kept down to about 2 to 4 per cent, so that one absorber would extract all the gasoline, by using a smaller quantity of gas in the tests.

Tests 11 to 16 show the results obtained from "line L" and "low field" gas with "straw oil" as the absorbent. The yields were not quite as high as those obtained with "mineral seal oil."

In using one absorber for field tests it is recommended that about 100 cubic feet of gas be used at the rate of 100 cubic feet per hour, with 1,750 c. c. of oil.

LARGE-SCALE EXPERIMENTAL PLANT AND ITS OPERATION.

While the tests with the small-scale absorber were under way, tests on a much larger scale were made with the plant shown in figure 3. This plant was capable of continuous operation as natural gas was continuously passed through the absorbing oil, and the oil, after leaving the absorbers charged with gasoline, was pumped to steam stills, where the gasoline was removed and the oil pumped back to the absorbers to receive another charge of gasoline. The plant had a capacity of 15,000 to 30,000 cubic feet per hour.

CIRCULATION OF GAS AND OIL.

The natural gas, which is brought in from a pipe line, enters the absorbing tank at c and the oil enters at b. They pass into the T pipe d, and the mixture passes from there through many small holes

into the oil contained in the absorber.   The gas bubbles up through the oil and passes out of the absorber as shown and returns to the pipe line.
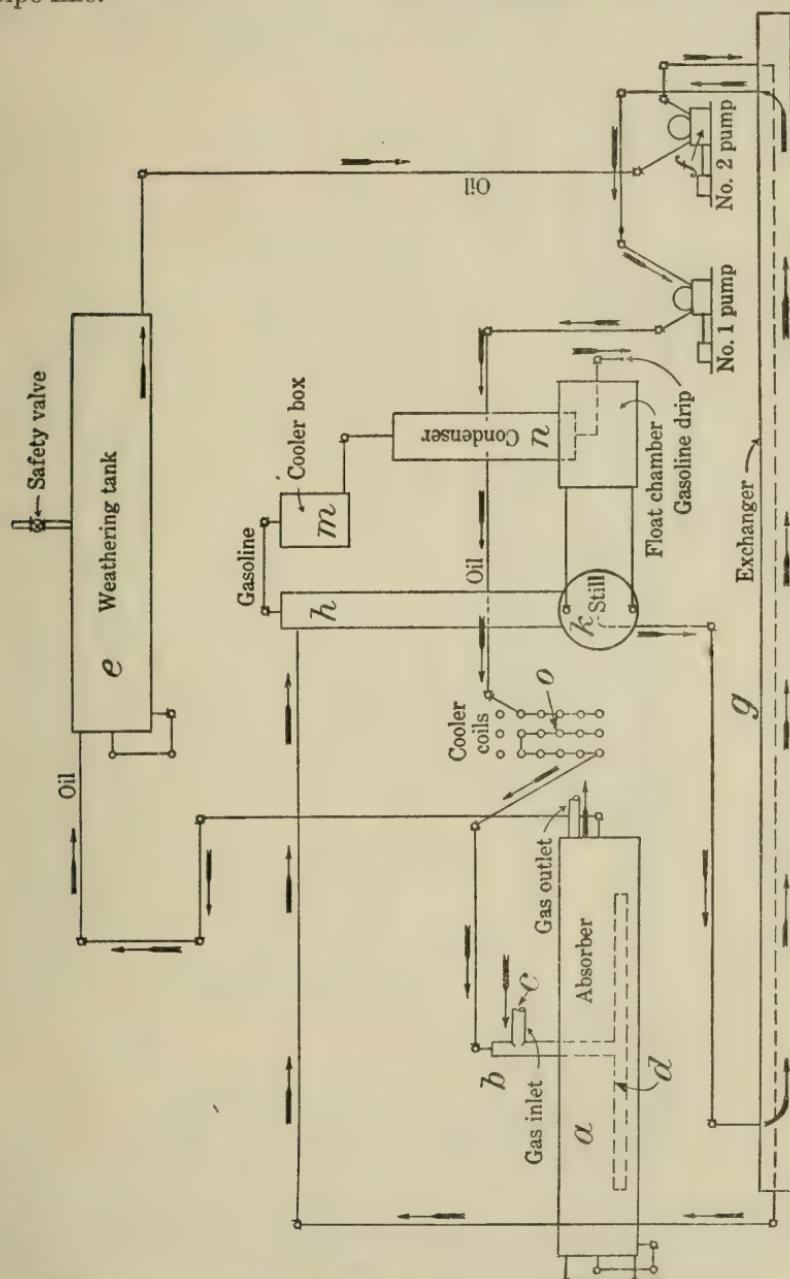
FIGURE 3.—Experimental plant for absorbing gasoline from natural gas.

The oil charged with gasoline passes first to the weathering tank e, where the lighter parts of the gasoline are released through the safety valve.   Next the oil enters the pump f and is pumped through the

heat exchanger g into the rock tower h of the steam still k, where the gasoline is distilled from the oil with live steam. The cooler m separates the water (condensed steam) from the gasoline, which is condensed in the condenser and flows out of the system at the gasoline drip.
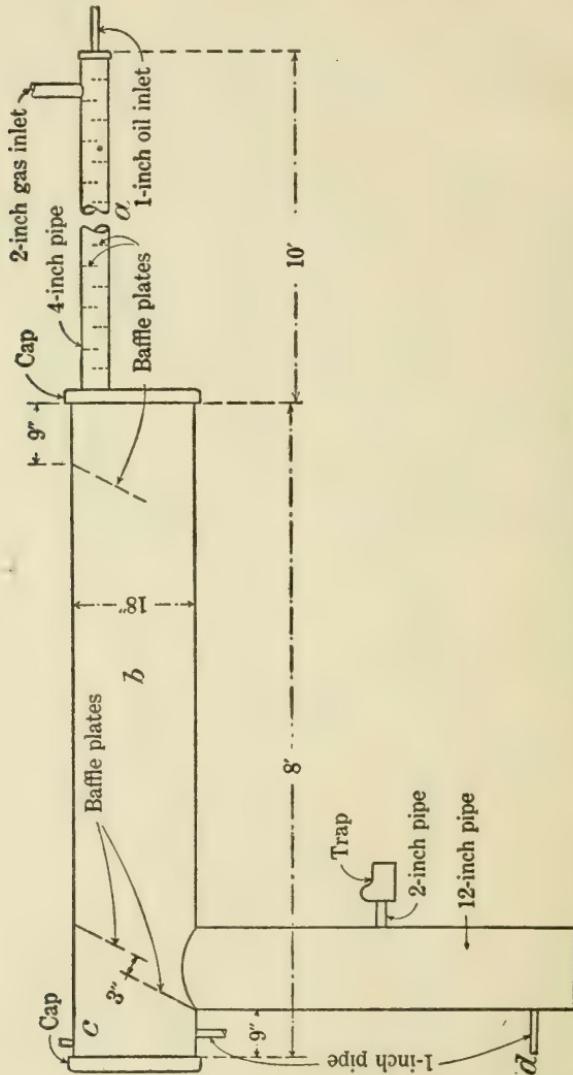
FIGURE 4.—Horizontal absorber, with baffle plates.

The hot oil, after having been freed of its gasoline, is passed through the heat exchanger g and heats the oil passing to the still and from No. 1 pump is forced through the cooling coils o, on which running water drops. The cooled oil then passes into the absorber a to receive another charge of gasoline. The operation is continuous, the oil being used over and over again.

ABSORBERS.

In addition to the type of absorber shown in figure 3 and in detail in figure 6, two other types of absorbers were used as shown in figures 4 and 5. In the absorber (No. 4) illustrated in figure 4 the gas and oil enter as shown, splash together against the baffle plates, and pass through the pipe a into the main pipe b. The gas leaves the absorber at the point c, and the oil, charged with gasoline, leaves at the point d. In the vertical or tower absorber (No. 5), illustrated in figure 5, the oil enters as shown and drops onto and through a column of stones each about the size of a man's fist. The gas enters near the base of the tower and flows countercurrent to the oil and out of the gas pipe at the top of the column. In the horizontal absorbing chamber (No. 6), shown in figure 6, the oil and gas flow through a vertical pipe and along a horizontal perforated pipe near the bottom of the chamber, whence the gas rises through the oil.

The steam still used in the tests is shown in figure 7. The oil charged with gasoline entered at the top of the stone column $a;$ live steam entered the still through the T pipe b. The oil, freed of its gasoline, left the still at c.

REMOVAL OF GASOLINE.

The cooling box in which the steam in the gasoline was condensed and the water returned to the still is shown in figure 8. The condensed steam was returned to the still at $a;$ the gasoline vapors passed through b to the cooler.

Figure 9 shows the condenser where the gasoline vapors were condensed and removed from the system.
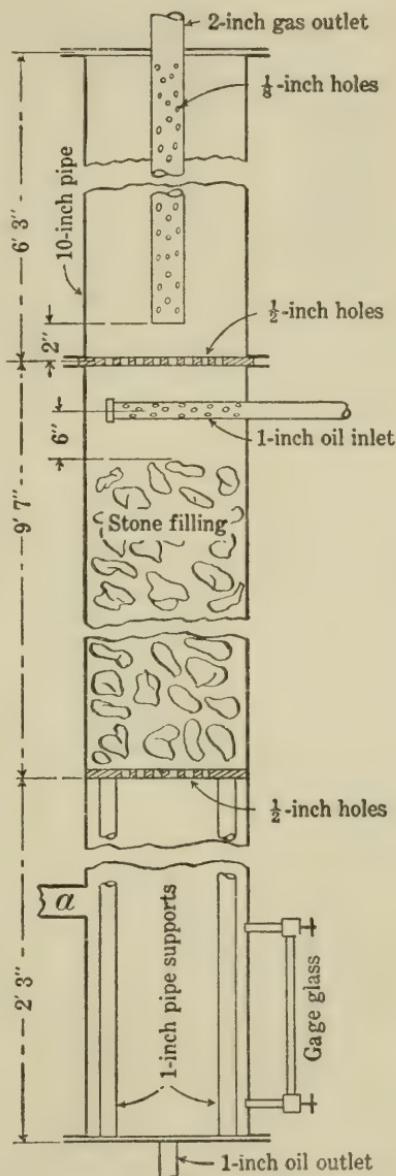
FIGURE 5.—Tower absorber, filled with stones.

The heat exchanger used in the experiments is shown in detail in figure 10. The oil flowing from the absorber to the still passed
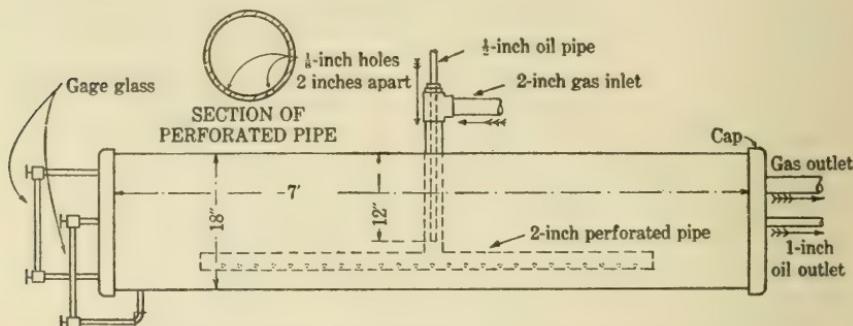
FIGURE 6.—Horizontal absorber, in which gas bubbles through the oil.

through the inside pipe and was heated by the hot oil from the still which passed through the outside pipe. The coils over which water
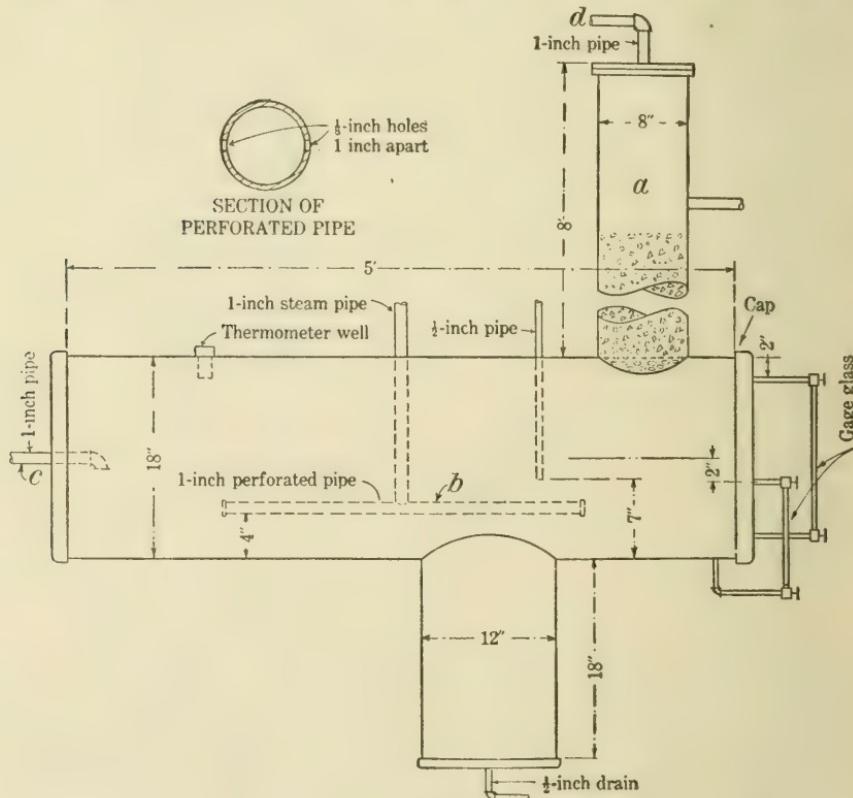
FIGURE 7.—Steam still for removing gasoline from absorbent.

flowed to cool the hot oil before it passed again into the absorber are shown in figure 11.
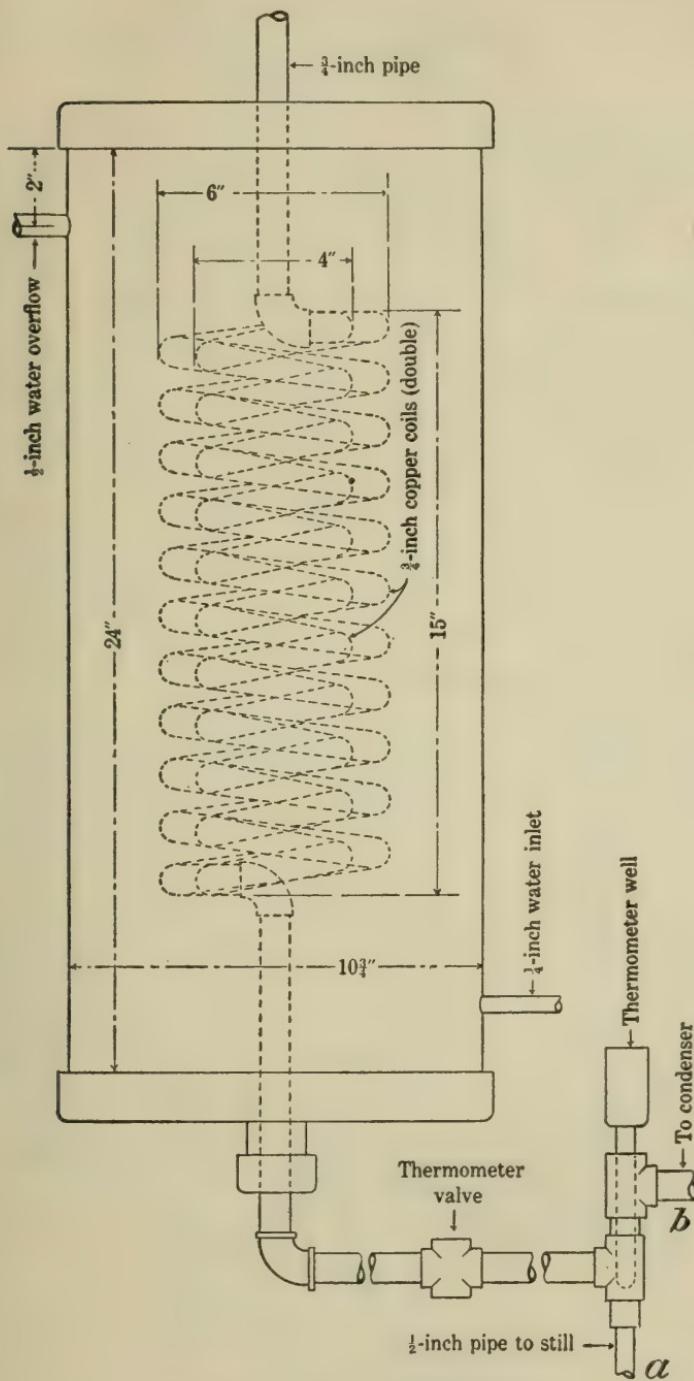
FIGURE 8.—Cooler box of condensing still.
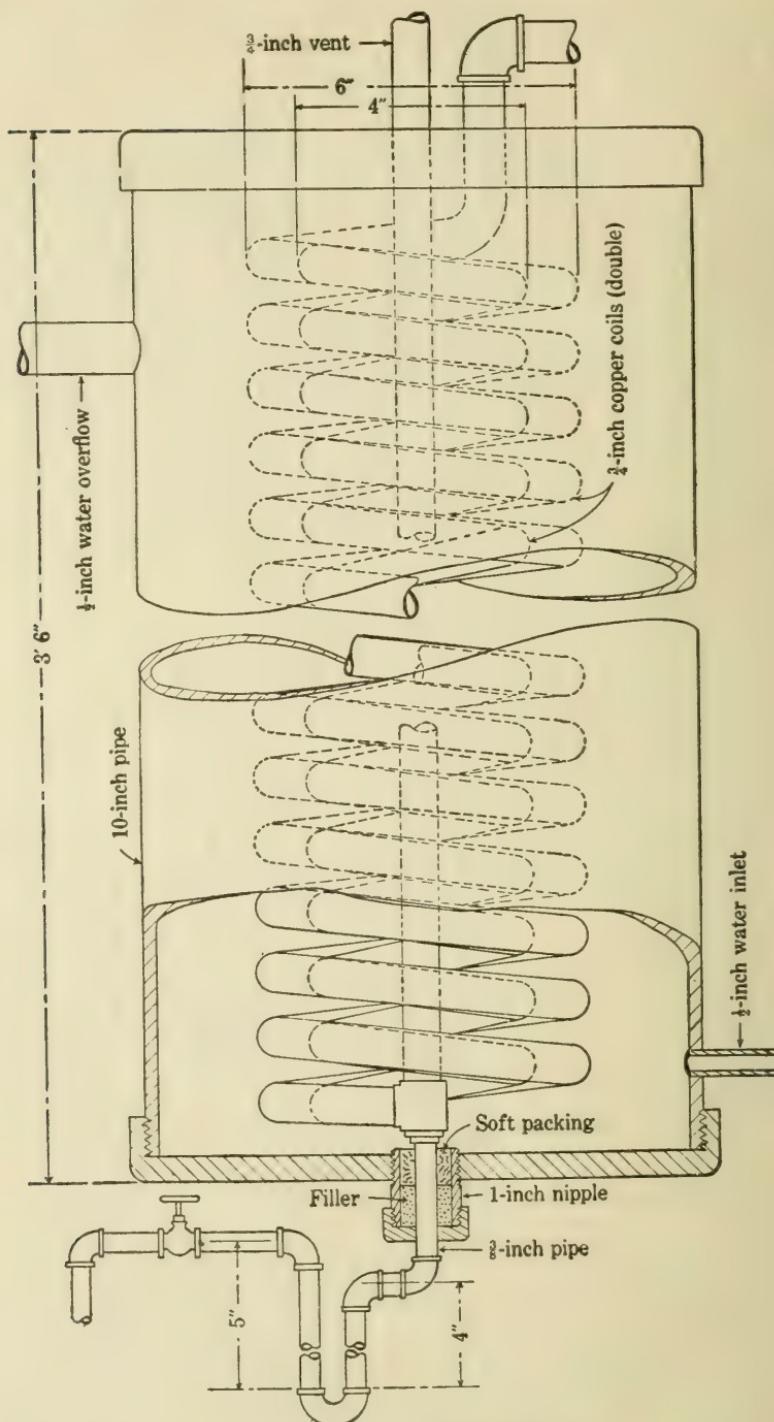
FIGURE 9.—Condenser for removing gasoline.

The weathering tank, where the lighter constituents of the gasoline were permitted to escape through a relief valve, is shown in figure 12.

REGULATION OF OIL FEED.

Oil in the still could not exceed a certain height because of the float shown in figure 13. When the oil exceeded the proper level, the ball a was raised, opening a valve b and allowing oil to flow from the still to a pump and from there around the circuit.

RESULTS OF TESTS WITH HORIZONTAL ABSORBERS.

Table 2 shows the results of tests with different absorbers on "low field" natural gas and "line L" natural gas. Each test was of four hours' duration and was conducted at the pressure of the gas line, about 225 pounds per square inch. In the first four tests more gaso-
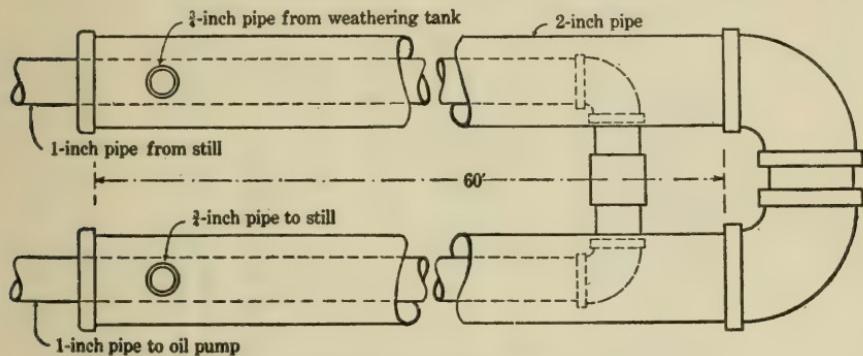
FIGURE 10.—Heat exchanger.

line was obtained from "low field" gas with absorber No. 2 than when absorber No. 4 was used. The same is true of "line L" gas, although in both cases the difference is slight. The pressure on the still was kept at about 2 to 3 pounds per square inch. The gas as it came from the lines had a temperature of about 46° to 53° F. The oil, after it left the stills and was cooled by passing through pipes upon which running water fell, had a temperature of about 80° F. The temperature of the oil charged with gasoline, after it had been heated in the "heat exchanger" and before it entered the still, was about 120° to 140° F. The "heat exchanger" heated the oil before it entered the still from a temperature of about 60° to 70° F. to a temperature of about 120° to 140° F.

In test 6, to show the effect of high temperature of the absorbing oil in decreasing the gasoline yield, the oil was given a temperature of about 90° F., which was about 10° higher than the previous tests, This rather slight increase in temperature made an appreciable dif-
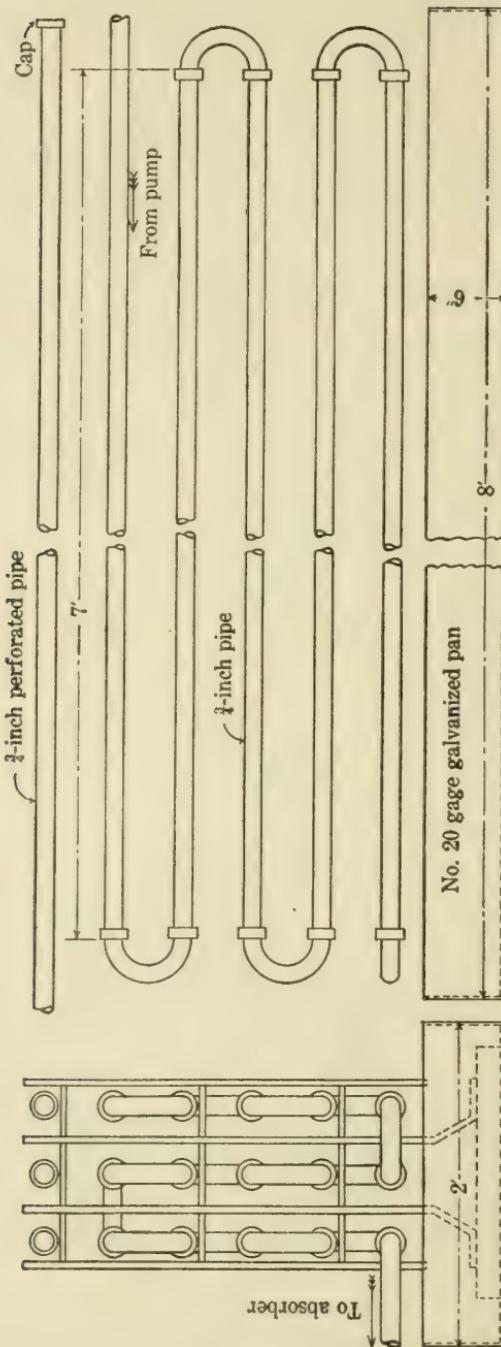
FIGURE 11.—Coils for cooling the hot oil from the still.

ference in the yield, as it was decreased about 0.3 pint of gasoline per 1,000 cubic feet of gas.
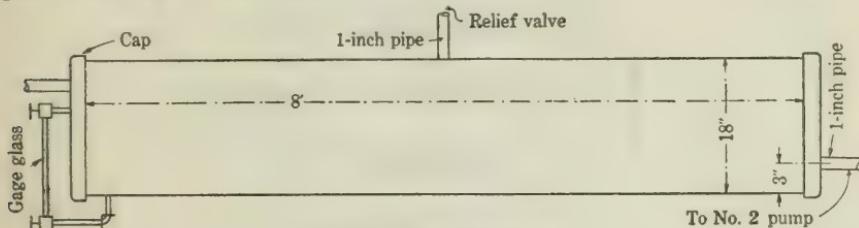
FIGURE 12.—Weathering tank.

The three different kinds of absorbers used in the tests are given the same numbers (Nos. 4, 5, and 6) as the illustrations that show
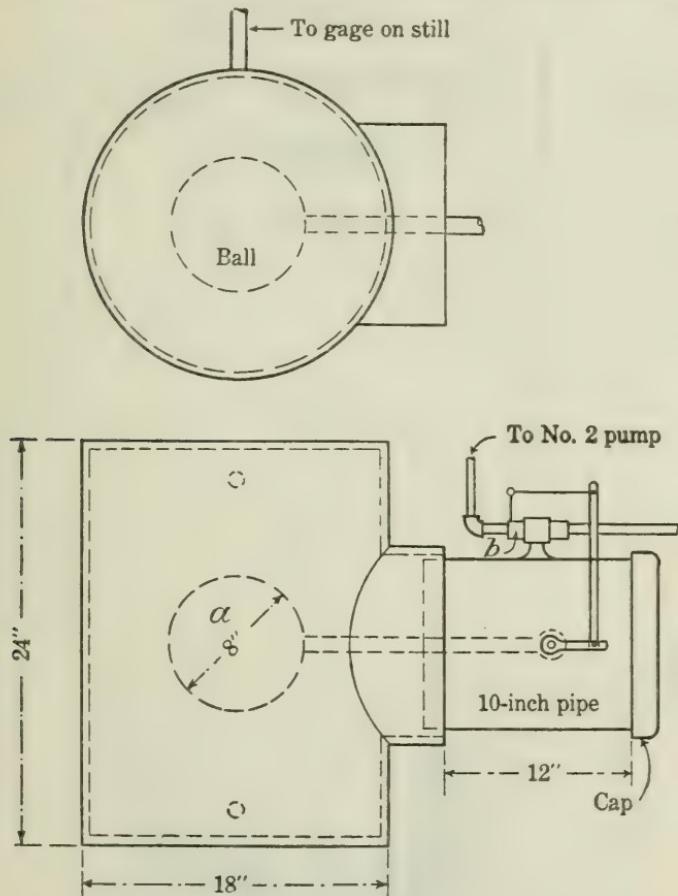
FIGURE 13.—Float for controlling height of oil in still.

them in detail (see figs. 4, 5, and 6). Figure 3 shows the plant as equipped with absorber 6. In each case it will be observed that greater yields of gasoline were obtained when absorber 5 was used.

TABLE 2.—*Data on continuous extraction of gasoline from natural gas with experimental plant.*

"Low field" gas.

| Item	Test 1. Absorber No. 6. Jan. 28, 1916.					Test 2.a Absorber No. 4. Jan. 29, 1916.				
	1 p.m.	2 p.m.	3 p.m.	4 p.m.	5 p.m.	1 p.m.	2 p.m.	3 p.m.	4 p.m.	5 p.m.
Pressure at inlet to absorber, pounds per square inch	3	3	3	2	3	2.5	2.5	2.5	2.5	2.5
Pressure on still, pounds per square inch			239.4					219.4		
Temperatures, ° F.:										
Gas inlet to absorber	52	54	52	54	56	50	50	50	50	50
Oil inlet to absorber	74	79	79	79	79	84	82	78	74	76
Oil inlet to still	134	121	141	138	122	126	118	124	124	142
Oil outlet from still	208	208	209	208	208	210	210	210	210	210
Vapor outlet from still	210	208	209	212	210	208	206	206	206	206
Vapor outlet from cooler	154	168	164	162	154	172	170	170	170	174
Cooling water	52	52	52	52	52	52	52	52	52	52
Still	216	215	216	215	216	216	216	216	216	216
Oil outlet from absorber	65	70	70	70	70	76	62	67	67	70
Specific gravity of absorbing oil, ° B.:										
At inlet to absorber	34.9	33.6	33.6	33.6	33.6	35.1	35.3	35.6	35.9	35.9
At outlet from absorber	37.7	37.2	37.2	37.6	37.6	35.8	36.9	36.5	36.2	36.5
Yield of gasoline, c. c.		9,000	9,500	9,600	10,000		9,800	9,900	10,500	10,200
Specific gravity of gasoline, ° B.		82.1	82.5	82.3	82.3	81.7	81.7	81.1	81.4	81.7
Amount of gas passed, cubic feet			63,000					60,000		
Yield of gasoline per 1,000 cubic feet, pints			1.2775					1.420		
Rate of gas flow, cubic feet per hour			15,750					15,000		
Rate of oil flow, gallons per 1,000 cubic feet of gas			9.1					7.1		
Absorption percentage			3.7							

"Line L" gas.

Item	Test 3.						Test 4.			
Absorber No.	6						4			
Date of test	Jan. 24, 1916.						Jan. 19, 1916.			
Time	2 a. m.	3 a. m.	4 a. m.	5 a. m.	6 a. m.	9 a. m.	10 a. m.	11 a. m.	12 m.	1 p. m.
Pressure at inlet to absorber, pounds per square inch	219						233[a]			
Pressure on still, pounds per square inch	2	2	2	2	2	2	2	2.5	2.75	2
Temperatures, ° F.:										
Gas inlet to absorber	52	52	50	52	52		48	48	48	48
Oil inlet to absorber						76	80	78	78	64
Oil inlet to still						114	122	120	120	120
Oil outlet from still	208	176	210	198	198	212	212	212	210	212
Vapor outlet from still	210	212	214	214	212	208	210	208	210	210
Vapor outlet from cooler	170	186	184	156	144	162	160	158	158	160
Cooling water	52	52	52	52	52		58	58	58	58
Still	214	214	216	214	214	216	216	216	216	216
Oil outlet from absorber						62	62	62	62	62
Yield of gasoline, c. c.		5,500	6,200	4,700	6,250		6,080	6,000	5,570	5,300
Specific gravity of gasoline, ° B			.759				79.9	80.6	80.6	79.6
Amount of gas passed, cubic feet			62,920					61,600		
Yield of gasoline per 1,000 cubic feet, pints			.759					.819		
Rate of gas flow, cubic feet per hour			15,730					15,400		
Rate of oil flow, gallons per 1,000 cubic feet of gas			5.13					8.4		

a This test was made with full-line pressure.

EXTRACTION OF GASOLINE FROM NATURAL GAS.

TABLE 2.—Data on continuous extraction of gasoline from natural gas with experimental plant—Continued.

Item.	"Low field" gas. Test 5.b Absorber No. 4 Jan. 27, 1916.									"Line L" gas. Test 6.b Absorber No. 6 Jan. 27, 1916.								
Time	8 a.m.	9 a.m.	10 a.m.	11 a.m.	12 m.	1 p.m.	2 p.m.	3 p.m.	5 p.m.	8 a.m.	9 a.m.	10 a.m.	11 a.m.	12 m.	1 p.m.	2 p.m.	3 p.m.	1 p.m.
Pressure at inlet to absorber, pounds per square inch	2	3	2	3	2.5	2.5	2.75	2.75	2.5	2		3	3	2.5	2.75	3	3	3
Pressure on still, pounds per square inch				241.4										214.7				
Temperature, °F.:																		
Gas inlet to absorber	46	46	46	46	46	46	46	46	46	46	60	60	60	61	62	64	63	62
Oil inlet to absorber	82	80	86	86	86	86	81	88	88	87	97	92	90	97	80	88	80	92
Oil inlet to still	122	128	134	128	128	126	126	141	141	130	132	120	139	139	132	132	138	144
Oil outlet from still	210	210	210	210	210	210	210	208	210	208	211	208	208	212	208	206	209	210
Vapor outlet from still	208	210	208	206	201	208	208	208	208	217	214	212	211	212	211	202	211	212
Vapor outlet from cooler	166	170	168	161	168	168	158	168	168	190	192	166	182	156	116	102	200	184
Cooling water	73	73	73	73	73	73	73	73	73	73	73	73	73	73	73	73	73	73
Still	216	218	216	216	216	216	216	216	216	217	216	216	216	216	214	211	216	216
Oil outlet from absorber		76	77	77	78	78	76	80	80		77	72	76	78	78	81	86	86
Specific gravity of absorbing oil, °B.:																		
At inlet to absorber		31	33.9	33.9	33.9	34.1	31	33.9	33.9		35.1	35.1	35.0	33.3	33.9	35.6	35.5	35.5
At outlet from absorber	35.8	35.7	35.7	35.7	31.6	31.6	31.8	34.5	31.6		37.2	37.1	36.8	36.6	37.6	36.1	36.9	36.9
Yield of gasoline, c. c.	7,850	6,730	7,850	9,250	8,750	9,300	10,250	8,300	8,100		6,000	6,500	8,130	6,100	7,250	9,100	7,250	7,250
Specific gravity of gasoline, °B.	91.6	87.5	91.6	80.6	91.5	91.5	91.6	91.6	91.5		77.0	78.7	78.6	78.7	78.6	78.0	78.6	78.6
Amount of gas passed, cubic feet					121,800									123,500				
Yield of gasoline, pints per 1,000 cubic feet					1.152									0.993				
Rate of gas flow, cubic feet per hour					15,200									15,125				
Rate of oil flow, gallons per 1,000 cubic feet of gas					5.3									8.8				
Absorption percentage					2.6									2.2				

b This test was made to determine the absorbing power of oil at a high temperature.

TESTS WITH TOWER ABSORBER.

With the experimental plant a number of tests were made in which the tower absorber (No. 5) shown in figure 5 was used. The results are given in Table 3, with those of a test made on the same day with absorber 4, shown in figure 4. The results are much in favor of the tower absorber. In fact, an arrangement like that shown in figure 5 has been found, from long experience by technical gas men, to be the most efficient method of washing or scrubbing any gas, although there are various other methods of introducing a spreading or contact surface, such as the use of clay tile or wooden lattice work.

The oil enters above the stones and flows through the interstices between them, covering each pebble with a thin film and exposing a large surface to the rising gas. The gas enters near the bottom of the absorber and first encounters oil more or less charged with gasoline. Some gasoline is removed from the gas at the start, and more is removed as the gas travels upward. Finally the gas, almost stripped of its gasoline, comes in contact with fresh oil which absorbs the remaining portions of the gasoline from the gas. The results of these tests are shown in Table 3.

TABLE 3.—*Results of comparative tests with absorbers No. 4 and No. 5.*

[Tests performed Mar. 3, 1916, with "low field" gas.]

Item.	Tower absorber (No. 5).				Baffle plate absorber (No. 4).			
	8 a. m.	9 a. m.	10 a. m.	11 a. m.	8 a. m.	9 a. m.	10 a. m.	11 a. m.
Pressure at inlet to absorber, pounds per square inch.	222	215	211	211	225	220	216	215
Pressure on still, pounds per square inch	3	3	2.75	2.75	3	3	2.75	2.75
Temperatures, ° F.:								
Oil	58	64	66	68	66	66	66	68
Oil outlet from still	207	210	208	209	212	212	212	210
Vapor outlet from cooler	142	170	164	176	170	172	184	172
Cooling water	52	52	54	52	52	52	52	52
Still	218	216	216	216	216	216	216	215
Oil outlet from absorber	54	58	60	62	60	58	60	68
Specific gravity of oil, ° B.:								
Oil at inlet to absorber	34.2	33.7	33.5	34.4	34.5	34.5	34.5	34.4
Oil at outlet from absorber	36.4	36.2	36.0	35.8	35.0	35.2	35.0	34.4
Yield of gasoline, c. c		17,000	16,000	16,310		9,200	9,600	11,300
Specific gravity of absorption gasoline, ° B		85.2	85.5	85.8		80.3	80.3	82.3
Specific gravity of refrigerator gasoline, ° B *a*		91.1	91.8	90.5		90.3	92.0	90.6
Volume of refrigerator gasoline, c. c		1,860	2,200	2,030		2,335	2,130	1,810
Amount of gas passed, cubic feet			73,800					
Yield of gasoline, pints per 1,000 cubic feet			1.57				1.18	
Rate of flow of gas, cubic feet per hour	24,600				21,600			
Gallons of oil circulated per 1,000 cubic feet of gas	7.9				8.7			

a Gasoline condensed from vapors that escaped from still.

EFFECT OF PRESSURE ON THE ABSORPTION OF GASOLINE FROM NATURAL GAS.

Table 4 shows the results of experiments made with the small absorber shown in figure 2, with "mineral seal oil" and "low field" gas, which show the variation in yield of gasoline with different pressures. Atmospheric pressure and pressures of 20, 40, 85, and 110 pounds per square inch were used. It will be noted that the yields vary from 0.71 pint to 1.19 pints of gasoline per 1,000 cubic feet of gas as the pressure was increased from atmospheric to 110 pounds per square inch. The maximum yield is undoubtedly obtained at 110 pounds, for, as shown in Table 1 (pp. 21–22), the yield at 235 pounds per square inch was not appreciably larger.

TABLE 4.—*Results of maintaining a constant feed with varying pressure.*

[Tests were made on "low field gas" with "mineral seal oil" as the absorbent.]

Item.	Test 1. Jan. 26, 1916, 2.48 to 3.58 p.m.			Test 2. Jan. 29, 1916, 2.25 to 3.40 p.m.			Test 3. Jan. 30, 1916, 9.35 to 10.45 a.m.			Test 4. Jan. 30, 1916, 1.05 to 2.25 p.m.			Test 5. Jan. 31, 1916, 8.15 to 9.37 a.m.		
Number of absorber used	3	4	5	3	4	5	3	4	5	3	4	5	3	4	5
Specific gravity of oil, ° B	34.2	34.2	34.2	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	34.2	34.2	34.2
Amount of oil used, c. c	1,750	1,500	1,500	1,750	1,500	1,500	1,750	1,500	1,500	1,750	1,500	1,500	1,750	1,500	1,500
Pressure on absorber, pounds per square inch, gage	(a)	(a)	(a)	20	20	20	40	40	40	85	85	85	110	110	110
Gas rate by meter, cubic feet per hour	79			85			85			75					
Flow of oil, c. c. per 1,000 cubic feet of gas	17,500	15,000	15,000	17,500	15,000	15,000	17,500	15,000	15,000	17,500	15,000	15,000	17,500	15,000	15,000
Gas consumed, cubic feet	100	100	100	100	100	100	100	100	100	102	102	102	100	100	100
Amount of liquid recovered, c. c	1,770	1,505	1,510	1,845	1,515	1,520	1,825	1,555	1,535	1,850	1,550	1,545	1,875	1,575	1,550
Specific gravity of liquid recovered, ° B	35.1	34.5	34.4	35	35.2	34.7	35.7	35	34.8	35.4	35.2	35.2	36.7	35.5	35.5
Temperature of liquid recovered, °F	68	67	66	66	68	69	64	68	69	68	70	70	64	66	66
Absorption of gasoline in liquid recovered, per cent	1.2	.6	.3	2.3	1.2	.5	2.6	1.0		2.8	1.02	.8		.75	
Increase in volume of liquid recovered, c. c	20	5	10	95	15	20	75	55	35	100	50	45	125	75	50
Increase in volume of liquid recovered, per cent	1.1	.3	.7	5.4	1.0	1.3	4.3	3.7	2.3	5.14	3.3	3	7.15	5.0	3.3
Sample for distillation test, c. c.	590	502	503	615	505	506	608	518	512	617	516	515			
Temperature of condenser bath, °F	48	48		46			46		(b)	52	52	52	48	48	48
Volume of distillate from sample, c. c.	7.0	3.0	1.5	14.0	5.8	2.7	15.6	5.2		20.8	5.2	4.0	21.1	1.0	.3
Temperature range of distillate, °F	166–260	199–260		160–260	138–260		130–260			120–260	130–260				
Volume of gasoline from sample, c. c.	21.0	9.0	4.5	42.0	17.4	8.1	46.8	15.6		62.4	15.6	12.0	63.3	3.0	1.2
Yield of gasoline, pints per 1,000 cubic feet of gas	.44	.19	.08	.888	.388	.171	.989	.33		1.31	.33	.25	1.34	.6	.025
Total yield of gasoline, pints per 1,000 cubic feet of gas	0.71			1.427			c1.489			1.89			1.97		

a Atmospheric pressure. b Sample lost. c Estimated loss 0.17 pint (see previous test).

OPERATION OF ABSORPTION GASOLINE PLANTS AT LOW PRESSURES.

Any gas, when brought into intimate contact with a liquid by mixing, is absorbed to some extent by the liquid, the amount absorbed varying greatly with the nature of the gas and also with that of the liquid. When gas is mixed with liquid under pressure, the greater the pressure to which the gas is subjected the larger is the amount (by weight) that is dissolved. A simple relation between the solubility of a gas and the pressure applied was discovered by Henry and has come to be known as Henry's law—namely, the amount of gas dissolved by a liquid is proportional to the pressure to which the gas is subjected. Henry tested several gases at pressures ranging from 1 to 3 atmospheres and found that the relation held quite closely. Exceptions to it, however, are not wanting. If the gas is very soluble in the liquid, the law does not hold.

The data given in Table 4 shows that under practically identical methods of operation the yield of gasoline increased with the pressure and that the maximum yield was obtained at 110 pounds pressure. In these tests the absorption of gasoline was less than 3 per cent, but the authors have found that this may be increased to 4 per cent, at high pressure, and the maximum yield obtained. The absorption percentage is calculated as follows:

$$\frac{\text{Volume of gasoline}}{\text{Volume of oil}} \times 100 = \text{absorption percentage.}$$

However, good results can be obtained at low pressures if the quantity of oil in circulation is increased. The authors obtained some experimental evidence on this point by keeping the pressure at atmospheric pressure and varying the oil circulation to determine what degree of saturation of the oil with gasoline is necessary for obtaining the maximum yield of gasoline at low pressures. The results of these tests are shown by the curve in figure 14. The abscissas show the yields in percentages of the total gasoline content, and the ordinates the absorption percentage. With an absorption of 3 per cent only about 10 per cent of the total gasoline content was obtained, whereas with 0.20 per cent absorption 80 per cent of the gasoline was obtained.

Hence if there were required 4 gallons of oil per 1,000 cubic feet of natural gas at 110 pounds pressure and 3 per cent saturation, there would be required $\frac{3}{0.20} \times 4 = 60$ gallons of oil per 1,000 cubic feet of gas at atmospheric pressure to obtain 80 per cent of the maximum yield.

It is well to bring out here that high pressures are not essential. Of course, a great deal of natural gas exists at high pressures, and hence can not be treated at low pressures; but, on the other hand, a great deal of gas can be treated at low pressures. This includes

so-called "dry" natural gas, used for domestic and factory purposes, and billions of feet per year of casing-head gas that is of too low grade to treat by compression methods. To the authors' knowledge no existing patent covers the basic process of treating natural gas at pressures of less than 30 pounds per square inch above atmospheric pressure.

At 25 pounds per square inch the amount of oil in circulation has to be increased 5 to 7 times the amount at high pressure to obtain the maximum amount of gasoline. However, operation of a plant at low pressure is more expensive, and such a plant costs more to build.
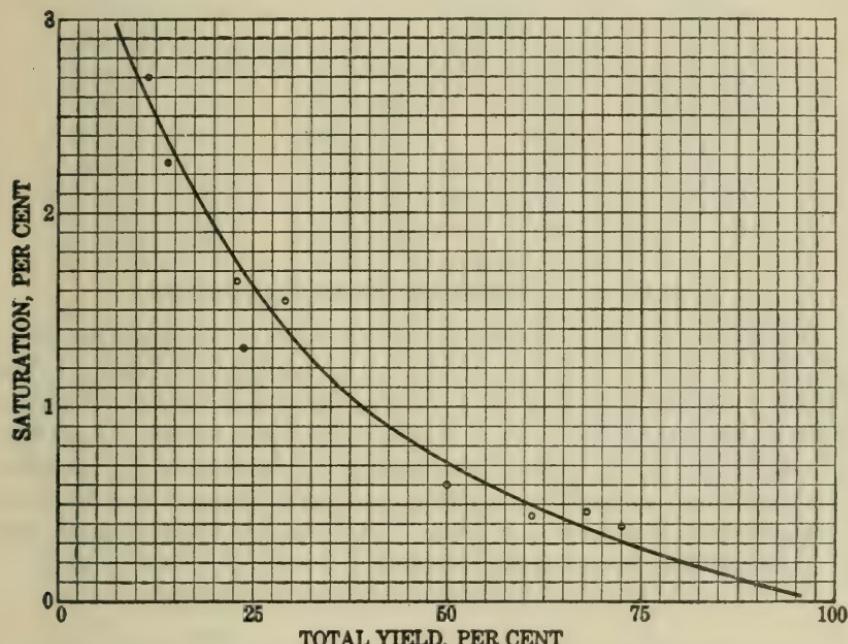
FIGURE 14.—Curve showing relation between the yield of gasoline and the percentage of absorption in oil, at atmospheric pressure.

AMOUNT OF OIL TO USE TO OBTAIN MAXIMUM YIELD OF GASOLINE.

A large number of tests were made with the different absorbers to determine the proper amount of oil to be used per 1,000 cubic feet of natural gas at high pressure in order to obtain the highest yield of gasoline. It was found that the best results were obtained with absorbers No. 4 and No. 6 (see figs. 4 and 6) when about 7 gallons of oil was circulated per 1,000 cubic feet of gas. With the tower absorber No. 5, shown in figure 5, good results could be obtained by circulating 4 gallons of oil per 1,000 cubic feet of gas. Instead of decreasing the amount of oil in this absorber, the practice of the authors was to keep the oil rate at about 7 gallons and increase the gas rate. The best results were obtained by passing about 28,000 cubic feet of gas per hour and circulating about 5 to 6 gallons of oil.

DISTILLATION TEST OF THE GASOLINE.

The gasoline obtained by absorption in "mineral seal oil" and steam distillation rather consistently had a specific gravity of about 80° B. The results of two of many distillation tests that the authors made of such gasoline are shown in the table following. The gasoline was from tests with the large-scale experimental plant shown in figure 3.

Results of distillation tests of gasoline obtained by absorption with "mineral seal oil" from experimental plant.

Gasoline obtained Dec. 22, 1915; specific gravity, 77.4° B.			Gasoline obtained Dec. 29, 1915; specific gravity, 80° B.		
Distillation temperature.	Volume of distillate.	Specific gravity of distillate.	Distillation temperature.	Volume of distillate.	Specific gravity of distillate.
° F.	Per cent.	° B.	° F.	Per cent.	° B.
80 to 102......	10		80 to 110......	10	91.8
102 to 124.....	20	88	110 to 124.....	20	89.0
124 to 138.....	30		124 to 136.....	30	86.7
138 to 152.....	40	78	136 to 146.....	40	83.4
152 to 168.....	50		146 to 158.....	50	80.4
168 to 182.....	60	72	158 to 172.....	60	77.4
182 to 202.....	70		172 to 188.....	70	73.3
202 to 232.....	80	68	188 to 208.....	80	70.2
232 to 250.....	88	65	208 to 244.....	90	65.0
Loss..........	12	....	244 to 290.....	93	63.1
			Loss..........	7	....

EVAPORATION LOSS FROM THE GASOLINE.

The results of tests to determine the loss by evaporation from different grades of gasoline are shown in the table following. The liquids were exposed in glass cylinders, 12 inches high and 4 inches in diameter, with a capacity of 1,000 cubic centimeters. The first column in the table shows the evaporation loss when the gasoline obtained from natural gas by the absorption process was exposed to the air in the open container. The second column shows the evaporation loss from refinery gasoline.

Results of tests to determine evaporation loss of gasoline.

	Gasoline from absorption process.	Refinery gasoline.
Specific gravity of gasoline at start, ° B..........	81.1	60.4
Temperature of gasoline, ° F....................	56	62
Temperature of room, ° F.......................	70	70
Volume of gasoline at start, c. c.................	1,000	1,000
Volume of gasoline after 24 hours, c. c............	895	976
Volume of gasoline after 48 hours, c. c............	840	955
Volume of gasoline after 72 hours, c. c............	800	924
Specific gravity of gasoline after 24 hours, ° B....	79.6	....
Specific gravity of gasoline after 48 hours, ° B....	76.5	....
Specific gravity of gasoline after 72 hours, ° B....	76	58
Temperature of gasoline after 24 hours, ° F.......	56	....
Temperature of gasoline after 72 hours, ° F.......	61	60
Evaporation loss of gasoline, per cent:		
Loss after 24 hours...........................	10.5	2.4
Loss after 48 hours...........................	16	4.5
Loss after 72 hours...........................	20	7.6

The gasoline obtained from natural gas by the absorption method lost by evaporation 10.5 per cent of its original volume in 24 hours, 16 per cent in 48 hours, and 20 per cent in 72 hours. The refinery gasoline, which is representative of most of that used in automobiles to-day, lost from one-third to one-fourth as much as the natural-gas gasoline.

VAPOR-TENSION TESTS OF THE GASOLINE.

Many vapor-tension tests were made of the gasoline, some of which are shown in the table following. It will be seen that the gasoline does not develop excessive pressure with rise of temperature and that it comes well within the specifications for gasoline that can be shipped in tank cars.

Results of vapor-pressure tests of gasoline obtained by absorption process.

Item.	Test 1.	Test 2.	Test 3.	Test 4.
Date of making test (1915)	Dec. 12	Dec. 16	Dec. 22	Dec. 23
Specific gravity of gasoline...........° B..	79	78	77.5	81.5
Vapor pressure at 70° F.............pounds per square inch..	1.25	1.0	.5	1.25
Vapor pressure at 90° F...................do....	1.50	1.5	1.0	2.0
Vapor pressure at 100° F..................do....	2.75	2.5	2.5	4.75

The rules of the Interstate Commerce Commission regarding the shipment of natural-gas gasoline follow.

REGULATIONS FOR THE TRANSPORTATION ON RAILROADS OF NATURAL-GAS GASOLINE.[a]

Liquefied petroleum gas is a condensate from the "casing-head gas" of petroleum oil wells, whose vapor tension at 100° F. (38° C.) to 90° F. (32° C.), November 1 to March 1, exceeds 10 pounds per square inch. Liquefied petroleum gas must be shipped in metal drums or barrels which comply with "Shipping Container Specifications No. 5" or in tank cars especially constructed and approved for this service by the Master Car Builders' Association. When the vapor tension at 100° F. (38° C.) exceeds 25 pounds per square inch, cylinders as prescribed for compressed gas must be used.

UNCONDENSED GASOLINE VAPORS IN GAS FROM STILL.

In distilling the gasoline from the "mineral seal oil" by means of steam, an appreciable quantity of uncondensed vapors escaped with the gas. Some of this vapor was liquefied by passing it through a pipe 1 inch in diameter and about 8 feet long placed inside another pipe 2 inches in diameter and 8 feet long. Compressed natural gas which had been used in place of steam to run one of the oil pumps was expanded through the larger pipe to cool and condense as much of the vapors in the inner pipe as possible. A temperature of 0° to 4° F. was obtained. The vapor pressure and other data regarding

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[a] From "Regulations of the Interstate Commerce Commission for the transportation of explosives and other dangerous articles by freight and express, and specifications for shipping containers." Published by the Bureau for the Safe Transportation of Explosives and Other Dangerous Articles, in January, 1912.

the condensed vapors obtained in tests of "line L" gas on December 28, 1915, with the plant shown in figures 3, were as follows:

In the test 130,000 cubic feet of natural gas was used, and 450 cubic feet of vapor passed through the condenser. The yield of gasoline obtained from the steam still during this test was 0.94 pint per 1,000 cubic feet of gas; the yield from the vapor passing through condensing pipe was $3\frac{1}{4}$ gallons per 130,000 cubic feet of natural gas, or 0.2 pint per 1,000 cubic feet, making a total yield of 1.14 pints. This gasoline showed a vapor tension of 0.5 pound at 70° F.; $8\frac{1}{4}$ pounds at 90° F.; and 11 pounds at 100° F. The specific gravity of the gasoline that was caught in the condensing pipe was 94.9° B., and that of the gasoline from the still was 80° B. In large-scale operations the uncondensed vapors are treated in an auxiliary compressor plant for extraction of the gasoline.

EVAPORATION TEST OF GASOLINE CONDENSED FROM VAPORS.

The rate of evaporation of the gasoline condensed from vapors escaping from the still is shown in the table following. The table also shows the rate of evaporation of mixtures of the gasoline with naphtha having a specific gravity of 55° B., and of the naphtha alone.

Evaporation losses from the gasoline and mixtures of gasoline and naphtha.

	Mixture of 500 c. c. of gasoline and 500 c. c. of naphtha.	Mixture of 250 c. c. of gasoline and 750 c. c. of naphtha.	Gasoline.
Volume of sample, c. c	1,000	1,000	1,000
Temperature of room, ° F	58	58	58
Specific gravity, ° B	71.6	63.4	89.0
Volume after 6 hours	975	988	962
Volume after 18 hours	948	982	912
Volume after 24 hours	922	968	870
Volume after 30 hours	902	954	840
Volume after 42 hours	882	942	812
Volume after 48 hours	880	948	805
Volume after 72 hours	854	928	740
Specific gravity at end of 72 hours, ° B.	848	928	755
Percentage loss after 18 hours	5.2	3.2	13.0
Percentage loss after 48 hours	12	5.2	19.5
Percentage loss after 72 hours	14.6	7.2	24.5

COST OF AN ABSORPTION PLANT.

As a result of the experiments described, which were on a fairly small scale, work was started on a large plant capable of handling 60 million cubic feet of natural gas daily. Exact figures for the costs of installing such a plant can not be given. It is believed, however, that a conservative estimate, figured on plant capacity, is $1.50 to $2 per 1,000 cubic feet of gas handled per day for a plant with a daily capacity of 60 to 90 million cubic feet or more, to $2 to $4 for a plant with a daily capacity of 30 million cubic feet or less.

The returns are large. At a cost of $1.50 per 1,000 cubic feet of plant capacity, a plant to handle 60 million cubic feet per day would cost $90,000. If only 1 pint of gasoline were extracted from each 1,000 cubic feet of gas the yield per day from 60 million cubic feet would be 7,500 gallons. The gross income at 20 cents per gallon for gasoline would be $1,500 per day.

CONSTRUCTION OF LARGE-SCALE ABSORPTION PLANT.

As a result of the experimental work with the plant shown in figures 7 to 13 a large plant, having a capacity of approximately 60,000,000 cubic feet of natural gas per day, was constructed. This plant is operating successfully and producing 1.2 pints of gasoline per 1,000 cubic feet of gas. The gas used in this plant is treated at a pressure of about 235 pounds per square inch.

Ten absorbers of the vertical type are used in parallel; each one is 30 feet high and 30 inches in diameter. Hollow tile is used as filling to distribute the oil as it falls through the absorber and comes in contact with the gas. Fourteen vertical heat exchangers are connected in series with piping so arranged that any one of them can be cut out of service. Each exchanger consists of an 18-inch pipe, 18 feet long, containing thirty-one 2-inch tubes. The cold oil passes through the 2-inch tubes, and the hot oil, traveling in the other direction, passes around the tubes, thereby providing for an exchange of heat between the hot and the cold oil. The still consists of a sheet-iron boiler shell 8 feet in diameter and 26 feet long, with a stone tower 26 feet high. Six pipe connections arranged in T form introduce live steam into the still.

A view of the absorbers is shown in Plate I, B; the stills, condensers, and heat exchangers are shown in Plate I, A. A general view of the plant is shown in Plate II, A.

At a plant other than the one described above the absorbers consist of 20-inch pipe, 20 feet high, with a flange tapped for 8-inch pipe at the top and a 20-inch by 6-inch swedge at the bottom, welded on. One foot above the welded joint of the swedge nipple an 8-inch collar is welded to the side of tower for a gas inlet. The gas outlet is through the 8-inch opening in the flange at the top of the tower. Two feet below this flange six openings are tapped in a ring around the 20-inch tower and in these openings are screwed spray nozzles pointing downward, their center lines forming an angle about of 30° with the center line of the tower. These nozzles have $\frac{3}{16}$-inch openings behind which are inserted twist drills. The fresh oil is pumped through the nozzles at a pressure 100 pounds higher than the gas pressure, resulting in a fine spray or fog of fresh oil being directed downward against the upward stream of gas through the tower.

The tower is filled from a point 1 foot above the gas-inlet opening to a point 9 feet above it with wooden slats ½ inch by 6 inches in dimension, standing on edge, with the lengths of alternate layers at right angles to each other. The oil spray strikes these slats and trickles down over their surfaces in thin layers, thus offering a large surface contact with the upward stream of gas through them. The oil flows out through the swedge nipple at the bottom into a receiving tank, from which it is forced by the gas pressure of the system to the oil heat interchangers, and thence to the still.

Each tower as above described is designed for a capacity of 3,000,000 cubic feet of gas per day at 300 pounds gage pressure. The rate of oil feed is four gallons per 1,000 cubic feet. The idea sought to be embodied is the principle of countercurrent flow combined with intimate mixing by atomizing the oil and having fresh oil mingle with the gas at the last moment of contact between the two, when the gas is lean.

HEAT EXCHANGERS.

The heat exchangers for warming the cold oil from the absorbers with the hot oil discharged from the still are made up in units, each of which consists of a rectangular sheet-iron box, with welded corner joints and flanged cover. Each box is $7\frac{5}{8}$ inches wide, 40 inches high, and 20 feet long inside, and contains 16 pressed-steel, two-column, four-section, 38-inch, hot-water radiators fitting snugly between the walls of the box. The opposite ends of the alternate sections of the radiators have baffle plates extending to the top and bottom walls of the box, thus causing the hot oil from the still to flow back and forth through the spaces between the individual radiator sections in series from one end of the box to the other. This gives the oil a long path, at comparatively high velocity, favorable to a rapid interchange of heat. The cold oil from the absorbers flows through the inside of the radiators in the opposite direction, thus further increasing the efficiency of the heat exchange. The box itself is lagged with wood on the outside to reduce radiation losses. Two of these boxes in series are designed to have a capacity corresponding to 6,000,000 cubic feet of gas per day, or an oil flow of 17 gallons per minute.

STILL.

Two types of still are being installed, both of which are based on the same principle—to cause the incoming charged oil to be spread in thin layers over the hot evaporating surfaces. In one type the still tank is 48 inches in diameter and 12 feet high, with banks of pressed-steel radiators set in it one over the other; at the top a sheet-iron distributing box receives the charged oil and causes it to flow
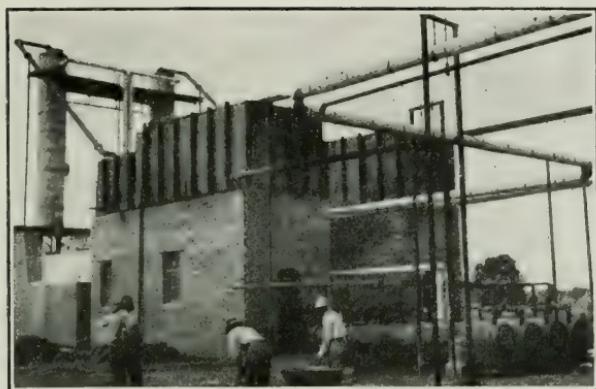
A. STILLS, CONDENSER, AND HEAT EXCHANGER.
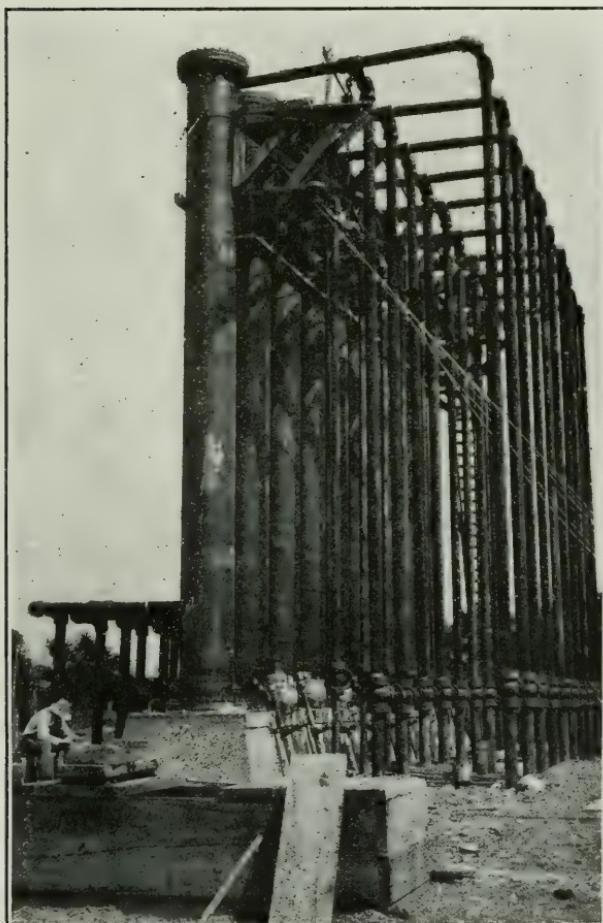
B. ABSORBER AT LARGE GASOLINE PLANT.
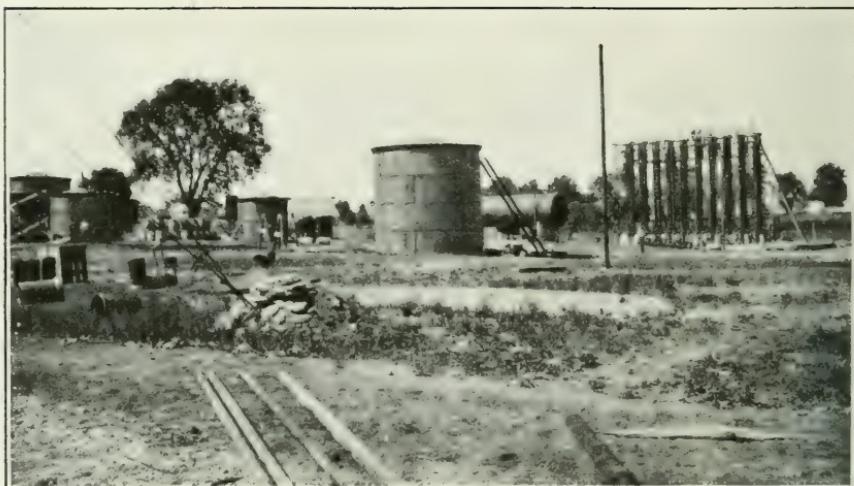
A. GENERAL VIEW OF LARGE GASOLINE PLANT.
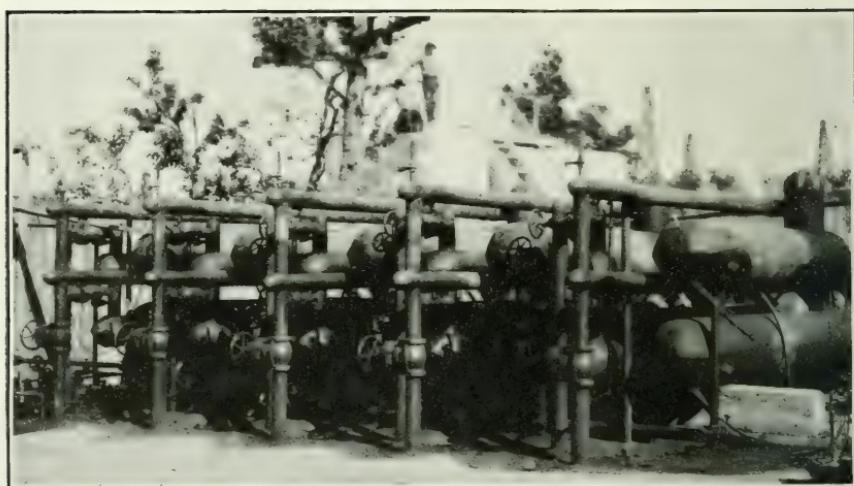
B. HORIZONTAL ABSORBERS IN LARGE GASOLINE PLANT.

over the top bank of radiators, and thence down to the next, and so on until it reaches the bottom, from where it is discharged to the heat exchangers.   The radiators are heated by live steam, and, as the oil passes over their hot surfaces, the gasoline is evaporated from the oil.

The other type of still consists of an old 5 by 12 foot boiler shell with the flues removed and one head replaced by a flanged head. This shell lies horizontally and within it are three sheet-iron troughs, one over the other, containing 1-inch steam coils.   The troughs are shallow and inclined so that the oil coming in at one end of the top trough flows over the hot coils and at the other end overflows into the trough below it, and so on until it reaches the bottom of the still, having been freed of its gasoline.   Provision is made for injecting live steam into the still when necessary.

CONDENSER.

A Young atmospheric condenser is used for condensing the gasoline vapor.   This consists of vertical cast-iron headers, containing separating baffles, with 2-inch pipe connecting the header towers in such manner that the vapor enters the bottom of one tower, encounters a baffle for separating the first condensate, then passes through two parallel lengths of 2-inch pipe to the next header and baffle, where condensate is further removed, then back through two more pipes to another separating header, and so on until three passes have been made, when all the vapor becomes condensed.   The pipes are cooled by water dripping over them from an overhead trough, and also by the cold air in wintertime.   The countercurrent flow, with continuous separation, makes it possible to segregate the first oily condensate from the later clear gasolines.   A cooler of this type to condense 2,000 gallons of gasoline per day with cooling-water temperature of 50° F. consists of three passes of doubled 2-inch pipe 20 feet long, with the necessary separating headers at each end.

OIL SEPARATORS.

In order to separate the absorbing oil from the gas, horizontal pipe separators are used, consisting of 16-inch pipe with 6-inch collars welded in the lower side and spaced 6 feet apart.   At these openings baffle plates are welded into the pipe on the downstream side of the opening, and extend across one-half the diameter of the pipe.   On the upstream side baffle plates are welded in, obstructing the top half of the pipe cross section.   These top plates deflect the incoming gas and oil mixture toward the drip openings and the force of the impact causes a separation of the oil from the gas.   In order to assist separation the top baffles are cut with a 120-degree segment opening, the lower edges of which are turned over against the direction of flow to serve as troughs for carrying the separated oil out of the stream of

gas to the sides of the pipe and thence to the drip openings. Four such drip openings are designed to separate all the oil from the gas, and a 16-inch separator is connected into an 8-inch line through welded swedge nipples.

CONSTRUCTION OF ABSORPTION PLANT NEAR CATLETTS-BURG, KY.

An absorption plant was constructed near Catlettsburg, Ky., that has a capacity of 80,000,000 cubic feet of gas per day.

The company has installed one 12-foot by 30-foot still with a 5-foot stone tower 35 feet high.   The condenser box is 16 feet wide, 25 feet long, and 10 feet high.   The auxiliary condenser is of the vertical tube type.   The oil circulation is 4 gallons of oil per 1,000 cubic feet of gas treated and the amount of gasoline obtained is 140 gallons per 1,000,000 cubic feet of gas.   The temperature in the still is maintained at 216° F.   Six heat exchangers are used, each containing 357 iron tubes 1 inch in diameter and 7 feet 10 inches long.   There are 10 absorbers, of the horizontal type, each 5 by 20 feet.   The oil cooler consists of six rows of 2-inch pipe, each row eight pipes high and 18 feet long.   Steam is generated at 125 pounds pressure from 300 boiler horsepower.   The vapors from the storage tanks and the noncondensable vapors from the still are compressed in a two-stage compressor with 10 by 12 inch and 4¾ by 12 inch cylinders.   The compressed gas is cooled by passing it through two rows of 2-inch pipe, each row being eight pipes high and 18 feet long.

At the time one of the authors of this report visited the plant trouble was experienced on account of the high temperature of the oil, water, and gas.   Also the gas compressor was not large enough to handle all of the vapors.

Plate II, *B*, shows the arrangement of horizontal absorbers at a plant in Oklahoma.

CALCULATED STEAM AND WATER REQUIREMENTS FOR AN ABSORPTION PLANT.

The amount of steam and water required for absorption-process gasoline plants of various sizes has been calculated from data accumulated by the authors in operating the plant shown in figure 3. These requirements are based on the fact that steam exhausts from various pumps and compressors around the plant into a low-pressure steam line and then into the steam stills, also that the overflow water from the condensers (at a temperature of 80° F.) is more than enough for the auxiliary condenser or cooler, so that the amount of condensing water required is computed for the main condensers only.   The amount of water required for cooling the compressed gas from the

weathering tank and condensers is very small and varies considerably in different plants, but for natural gas that contains about $1\frac{1}{2}$ pints of gasoline per 1,000 cubic feet is about 0.03 gallon of water per 1,000 cubic feet.

STEAM REQUIREMENTS.

In distilling gasoline from the oil heat is required for two purposes: First, to raise the temperature of the oil and gasoline to the vaporization point of the gasoline; and second, to supply heat absorbed by actual vaporization. Hence a knowledge of the specific heat of the oil and gasoline and of the latent heat of the gasoline is necessary.

The number of British thermal units required to raise the temperature of 1 pound of a substance 1° F. is called the specific heat of the substance.

The heat absorbed without change of temperature during a change of state, as from a solid to a liquid or from a liquid to a gas, is called the latent heat.

These constants have not been determined precisely for different grades of gasoline or oil, but are approximately as follows:

Latent and specific heats of petroleum products.[a]

Product.	Specific heat.	Tempera-ture.	Latent heat.
	B. t. u.	° *F.*	*B. t. u*
Kerosene, gravity 43° B	0.499	(b)	105. 4
Naphtha, gravity 56° B	.0510	175° F.	103. 5
Gasoline, gravity 65° B	.569	b 115° F.	100. 6
Gasoline, gravity 89° B	.580	b 70° F.	100. 2

[a] Redwood, Boverton, Petroleum, 1913, vol. 1, pp. 219–221.   [b] Initial boiling point.

In view of the fact that the exact constants for "mineral seal oil" and gasoline can not be given, the best that can be done is to use for "mineral seal oil" the constants as given in the above table for kerosene, and use for absorption-process gasoline the constants given for 89° B. gasoline. With this and other data the heat required in the stills can be calculated as follows:

Temperature of oil entering still, 135° F.
Temperature of vapors from still, 210° F.
Temperature change, 75° F.
Specific heat of "mineral seal oil," 0.50.
Weight of "mineral seal oil," 7 pounds per gallon.
Heat required to raise 1 gallon of "mineral seal oil" from 135° F. to 210° F.$=75\times.50\times7=262.5$ B. t. u. per gallon.
Specific heat of gasoline, 0.58.
Latent heat of gasoline, 100 B. t. u. per pound.
Weight of gasoline, 5.5 pounds per gallon.

Heat required to raise temperature of gasoline from 135° F. to 210° F.=75×0.58× 5.5=239.5 B. t. u. per gallon.

Heat required to vaporize gasoline=100×5.5=550 B. t. u. per gallon.

Hence the total heat required to vaporize gasoline=550+239.5=789.5 B. t. u. per gallon.

The authors' experiments have shown that the proper rate of circulation of oil through an absorption plant at high pressures is one where the mixture of oil and gasoline does not contain over 4 per cent by volume of gasoline.

Then for each volume of "mineral seal oil" the heat required to vaporize the contained gasoline is 0.04 × 789.5 = 31.58 B. t. u., and the total heat required for each gallon of "mineral seal oil" in circulation with its contained gasoline is 262.5 + 31.58 = 294.08 B. t. u.

Some of the steam entering the still is not condensed in the still but passes through to the auxiliary condenser without doing any useful work. To cover this loss and radiation losses the assumption can be made that the still has an efficiency of 80 per cent. Then the amount of heat required to be delivered to the still for each gallon of "mineral seal oil" circulated will be 294.05 ÷ 0.80 = 367.5 B. t. u.

In practice, the steam used is largely exhaust steam from pumps about the plant and enters the still at a pressure of about 3 pounds per square inch. Saturated steam at this pressure corresponds to a temperature of 219.4° F., and the thermal energy imparted to and contained in the steam in raising it to this temperature from 32° F. is 1,153.1 B. t. u. per pound. Condensed water leaving the still at about 210° F. has a heat content above 32° F. of 178 B. t. u. per pound. The difference is 975.1 B. t. u. per pound. Hence there will be required $\frac{367.5}{975.1} = 0.377$ pound of this exhaust steam for each gallon of oil circulated.

As stated above, this exhaust steam entering the still is largely exhaust steam from pumps about the plant. It is generated at a pressure of about 125 pounds per square inch to run the pumps. The boiler feed water available is the condensed water from the stills and the overflow from the auxiliary condensers. A feed-water temperature of about 200° F. may be depended upon. The heat content of saturated steam at 125 pounds pressure is 1,192.2 B. t. u. per pound, and that of water at 200° F. is 168 B. t. u. per pound. Therefore the available heat is 1,192.2 − 168 = 1,024.2 B. t. u. per pound of steam.

One boiler horsepower is equivalent to 33,479 B. t. u., hence $\frac{1,024.2}{33,479} = 0.0306$ boiler horsepower is required per pound of steam. It follows that for each gallon of "mineral seal oil" circulated, 0.377 × 0.0306 = 0.01154 boiler horsepower will be required per 1,000 feet of gas treated per hour.

WATER REQUIREMENTS FOR ABSORPTION PLANT.

The gasoline vapor leaving the auxiliary condensers has a temperature of 180° F. If this vapor is cooled to 60° F., and the specific heat of the gasoline is 0.58 and the weight of 1 gallon is 5.5 pounds, the heat given up in cooling is $(180-60) \times 0.58 \times 5.5 = 382.8$ B. t. u. per gallon. If the latent heat of gasoline is 100 B. t. u., the amount of heat given up in condensing 1 gallon is $100 \times 5.5 = 550$ B. t. u. The temperature of the water in the condenser ranges from 60° to 80° F., hence the amount of heat absorbed by the water is $20 \times 8.33 = 166.6$ B. t. u. per gallon of condensing water. Therefore the amount of water required for each gallon of gasoline condensed is $\dfrac{382.8+550}{166.6} = 5.6$ gallons. This water overflows from the condenser box into the auxiliary cooler and is more than enough for the latter.

WATER FOR OIL-COOLING COILS.

The oil comes from the heat exchanger at a temperature of approximately 135° F. and is cooled to at least 70° F. before it reenters the absorber. The specific heat of "mineral seal oil" is 0.50 and its weight is 7 pounds per gallon. Hence the amount of heat to be extracted is $(135-70) \times 7 \times 0.50 = 227.5$ B. t. u. The temperature of the water before flowing over the cooling coils is 60° F. and after cooling is 100° F., therefore the amount of heat absorbed per gallon of cooling water is $(100-60) \times 8.333 = 333$ B. t. u. per gallon, and for cooling purposes $\dfrac{227.5}{333}$ or 0.705 gallon of water is required per gallon of "mineral seal oil" circulated.

The table following shows the steam and water requirements for absorption plants treating natural gas containing varying amounts of gasoline.

Suppose that the steam and water requirements are wanted for a high-pressure absorption plant to treat 60,000,000 cubic feet of natural gas containing $1\frac{1}{2}$ pints (or 0.1875 gallon) of gasoline per 1,000 cubic feet of gas. The oil rate to use is 4.69 gallons per 1,000 cubic feet of gas treated, and the boiler horsepower required to treat 60,000,000 cubic feet per day, or 2,500,000 cubic feet per hour, is $2,500 \times 0.054 = 135$ boiler horsepower. The quantity of water for the plant is $4.35 \times 60,000 = 261,000$ gallons per 24 hours.

It is best to increase the calculated values as given by the authors by 20 per cent, and to install double this boiler capacity to permit cleaning the boilers without shutting down the plant.

Quantities of steam and water required per 1,000 cubic feet of gas treated by absorption plant at high pressures.

Steam for distillation.			Water supply.[a]			
Yield of gasoline.	Oil circulated.	Boiler horsepower-hours.	Condensers.	Oil cooler.	Gas cooler.	Total.
Gallons.	*Gallons.*		*Gallons.*	*Gallons.*	*Gallons.*	*Gallons.*
0.0625	1.56	0.018	0.35	1.1	0.01	1.46
.125	3.10	.036	.7	2.2	.02	2.92
.1875	4.69	.054	1.05	3.3	.03	4.35
.250	6.25	.072	1.4	4.4	.04	5.84
.375	9.40	.109	2.1	6.6	.06	8.76
.50	12.5	.144	2.8	8.8	.08	11.68
.625	15.6	.180	3.5	11.0	.10	14.6
.75	18.75	.216	4.2	13.2	.12	17.52
1.00	25.00	.2885	5.6	17.6	.16	23.36
1.50	37.50	.433	8.4	26.4	.24	35.04
1.75	43.75	.505	9.8	30.8	.28	40.88
2.00	50.0	.577	11.2	35.2	.32	46.72
3.00	75.0	.865	16.8	52.8	.48	70.08
4.00	100.0	1.154	22.4	70.4	.64	93.44
5.00	125.0	1.443	28.0	88.0	.80	116.8

[a] Includes water for cooling compressed gases from weathering tank and still.

APPLICATION OF THE ABSORPTION PROCESS TO CASING-HEAD GAS.

An interesting possibility lies in the application of the absorption process to casing-head natural gas that is at present being treated or can be treated by compression-and-condensation methods. To gain information on this point the authors made some tests with a small absorption plant of casing-head gas at a compression and condensation plant near Charleston, W. Va. In this compressor plant the natural gas is withdrawn from the oil wells under a pressure of about 17 inches of mercury, absolute (about 8.3 pounds per square inch), and is delivered at about atmospheric pressure to a compressor, where it is compressed at a pressure of about 30 pounds per square inch. The gas is cooled, the condensate removed, and is then compressed in the high-stage compressor at a pressure of about 180 pounds per square inch. Next the gas is passed through water-cooled tanks to the accumulator tanks, where the condensate is drawn off. The residual gas, which leaves the high-stage accumulator, at a pressure of about 110 pounds per square inch, is sold to a natural gas company.

DATA ON COMPRESSION PLANT PRACTICE.

Data obtained by the authors for a 24-hour run on the compression plant follows:

Data on compression plant near Charleston, W. Va.

Amount of natural gas used............................cubic feet.. 378,000
High-pressure accumulator tank:
    Pressure in tank.........................pounds per square inch..   180
    Yield of gasoline..gallons..   1,714
    Gravity of gasoline....................................... ° B..   92
    Vapor tension of gasoline at 100° F........pounds per square inch..   23
Low-pressure accumulator tank:
    Pressure in tank ....do....   30
    Yield of gasoline..gallons..   170
    Gravity of gasoline...................................... ° B...   750
    Vapor pressure of gasoline at 100° F.......pounds per square inch.. $8\frac{1}{4}$
Total yield from accumulator tanks...........................gallons..   1,884
Gasoline in stock tanks after reduction of pressure and after weathering:
Yield...gallons..   934
Specific gravity.. ° B..   87.4
Vapor tension at 100° F......................pounds per square inch..   13
Yield in accumulator tanks per 1,000 cubic feet of gas.........gallons..   4.98
Yield after "weathering" in stock tanks per 1,000 cubic feet of gas.do....   2.47

The last figure, 2.47 gallons of gasoline per 1,000 cubic feet of gas, represents the quantity of gasoline actually sold from the compressor plant. In other words, there was a weathering loss of $1,884 - 934 = 950$ gallons, or 50.4 per cent.

Tests of the weathered gasoline from the stock tanks showed that further "weathering" to reduce the vapor pressure to 9 pounds per square inch resulted in an additional loss of 15 per cent in volume and reduced the gravity to 86.7° B. Therefore the production of gasoline having a vapor pressure of 9 pounds per square inch was 2.1 gallons of gasoline per 1,000 cubic feet of natural gas treated in the plant, and the entire "weathering" loss to produce gasoline of 9 pounds vapor pressure was 57.9 per cent.

TESTS BY ABSORPTION PROCESS.

The first tests the authors conducted on casing-head natural gas, using the absorption process, were with a small absorber somewhat similar to that shown in figure 2 (p. 19), except that it was surrounded with four coils instead of one coil, and the gas passed through each of these coils successively. Also the absorber was of larger capacity, holding about 4,000 c. c. of oil, whereas the one illustrated in figure 2 held about 1,700 c. c. This reconstruction was necessary because casing-head natural gas is much richer in gasoline than the "dry" natural gas with which the absorber shown in figure 2 was used, hence more absorbing oil had to be used and longer contact provided between the oil and gas.

In some of the tests with the small absorber, the gas was used after it had passed through the low-stage compressor of the compression plant and before it had been cooled and gasoline condensed

out of it.   Other tests were made of residual gas from the compression plant to determine if more gasoline could be extracted from the gas after the compression plant had operated on it.   Table 5 following shows the results of these tests.

Test 1 was made of fresh casing-head natural gas at the plant near Charleston, W. Va., where the tests described on page 52 were conducted.   Test 2 was made of residual gas from the same plant after gasoline had been extracted from it by the compression method. Tests 3 and 4, which were conducted in the same manner as tests 1 and 2, were made at another compression plant situated near Charleston, W. Va.

TABLE 5.—*Results of tests of casing-head gas with small absorber.*

Source of gas	Compression plant No. 1.		Compression plant No. 2.	
	Fresh gas.	Residual gas.	Fresh gas.	Residual gas.
Test No.	1	2	3	4
Specific gravity of "mineral seal oil" used, ° B	36	36	36	36
Volume of oil used, c. c.	4,100	4,100	4,100	4,100
Gas pressure on absorber, pounds per square inch	32	132	26	123
Gas consumed, cubic feet	25	80	25	80
Liquid recovered:				
Volume, c. c.	4,775	4,325	4,635	4,450
Gravity, ° B	39.5	39.0	39.5	37.0
Temperature, ° F	70	68	77	77
Absorption percentage	4.8	0.5	4.9	1.3
Increase, c. c.	675	225	535	250
Volume increase, per cent	16.5	5.5	13.0	6.1
Sample for distillation, c. c.	531	541	464	556
Temperature of condenser, ° F	50	50	50	50
Distillate, c. c.	25.5	2.8	23.0	7.0
Gasoline extracted during test, c. c.	229.5	22.4	230	56
Gravity of gasoline, ° B		86.0		86.0
Gasoline, gallons per 1,000 cubic feet of gas	2.43	0.07	2.43	0.18

Test 1 showed that 2.43 gallons of gasoline could be extracted by absorption methods from the fresh casing-head gas used at the first plant, under a pressure of 32 pounds per square inch and an oil temperature of 70° F., as compared with 2.47 gallons of salable gasoline extracted by the compression and condensation method.   The residual gas from this compression plant (test 2) yielded only 0.07 gallon of gasoline per 1,000 cubic feet of gas.   In other words, the compression plant had extracted practically all of the gasoline from the gas, so nothing was gained by treating the residual gas from the compression plant by the absorption method.

The casing-head gas used at the second plant yields by the compression and condensation method the same amount of gasoline as that used at the first plant.   The same amount of gasoline was produced (test 3) from it by the absorption method as from the gas used at the first plant.   The yield of gasoline obtained from the residual gas

by the absorption method was slightly larger than that obtained by treating the residual gas from the first plant, being 0.18 gallon per 1,000 cubic feet of gas, or 72 gallons per 400,000 cubic feet of gas treated. It is believed, however, that with more efficient operation of the compression plant even this quantity could not be obtained. In other words, it seemed scarcely worth while to treat residual gas from these two compression and condensation plants by the absorption method. However, at some compression plants the extraction is not nearly so complete.

EXPERIMENTS WITH LARGE-SCALE ABSORPTION PLANT.

Experiments with the casing-head natural gas treated at the first compression plant described above were made with a large-scale absorption plant similar to that shown in figure 3. The natural gas was compressed to a pressure of 20 to 29.2 pounds per square inch in the low-stage compressor and then passed through the absorption plant. In only one case was the gas cooled after leaving the compressor and before entering the absorber. The results of these tests were as follows:

TABLE 6.—*Results of tests of casing-head gas with large-scale absorption plant.*

	Test 1.	Test 2.	Test 3.	Test 4.	Test 5.	Test 6.
Pressure of gas, pounds per square inch...	24	20	22	23	29.2	28
Rate of gas flow, cubic feet per hour.......	5,900	5,100	5,000	5,400	3,300	2,800
Rate of oil flow per 1,000 cubic feet of gas..	23.5	33.6	45.6	38	40.2	59
Yield; gallons per 1,000 cubic feet..........	1.69	1.99	1.91	1.90	a1.91	b2.24
Specific gravity of gasoline, °B.............	82	83	84	82	80	83

NOTE.—Oil entering tank was warm, owing to the fact that the oil absorbed heat from the gas.
a After passing cooler.
b Made on rainy day; rain lowered temperature of absorbing oil.

It will be observed that the yield of gasoline increased as the rate of oil flow was increased and the rate of gas flow was diminished, and that the largest yield was obtained with an oil flow of 59 gallons per 1,000 cubic feet of gas treated and a gas flow of 2,800 cubic feet per hour. This yield is not quite as large as that obtained by using the small-scale absorber (see Table 5), but undoubtedly if the gas had been cooled before it entered the absorber, and closer adjustments of oil and gas flow had been made, a larger yield could have been obtained with the large-scale absorption plant.

Experiments were also made with the large-scale absorption plant, using residual gas from compression plant No. 2, for comparison with the results of tests 3 and 4, shown in Table 5, which were made with a small absorber.

The oil circulation in these large-scale tests of residual gas varied between 2 and 16 gallons per 1,000 cubic feet of gas treated. The gravity of the oil after passing through the absorber was 46° B., as

compared to an original gravity of 36° B.   The rate of flow of the gas through the absorber was approximately 10,000 cubic feet per hour at a pressure of 110 pounds per square inch.   The gasoline recovered had a gravity of 86° B. and was not obtained in commercial quantities.   Large volumes of gas were absorbed by the oil that upon distillation could not be condensed at the temperature of the cooling water (64° F.).

These large-scale tests bear out the results obtained with the small absorber, namely, that no additional gasoline could be obtained by treating the residual gas from the compressor plant by the oil absorption process.

EVAPORATION TESTS.

Evaporation or "weathering" tests that were made of the gasoline obtained from the large absorption plant and compression plant No. 1 are shown in Table 7 following:

TABLE 7.—*Comparative evaporation tests of gasoline from compression and absorption plants.*

Source of gasoline.	Absorption plant.	Absorption plant.a	Low-pressure accumulator tank of compression plant.	High-pressure accumulator tank of compression plant.	Stock tank.b	Stock tank.b
Test No.	1	2	3	4	5	6
Size of cylinder tests were made in, c. c.	500	500	500	1,000	1,000	1,000
Duration of test, hours	8	5¼	6	2½	6	6
Gravity at beginning of test, °B.′	84.4	84	77	Above 92]	Above 92	Above 92
Gravity at end of test, °B.′	81.8	84	72.8	....	86	86
Total loss, per cent	15	12	18	44	40	40
Rate of loss per hour, per cent	1.9	2.3	3	17.6	6.7	6.7
Temperature of air, °F	49	74	46	46	....	....

a Placed near steam coil to hasten evaporation.
b After 45.5 per cent loss in transferring gasoline from accumulator tank to stock tank.

The more stable character of the gasoline produced by the absorption process is brought out by the foregoing evaporation tests. Tests 2 and 3 can be compared with tests 5 and 6, for they show the results of evaporating or "weathering" the final product obtained by both processes.   The average rate of loss per hour was over twice as great in the case of the gasoline obtained by the compression method.

VAPOR-PRESSURE TESTS.

Table 8 shows the results of comparative tests of vapor pressures of gasoline obtained by the compression method and by the absorption method.

TABLE 8.—*Results of vapor-pressure tests of gasoline made by absorption and by compression methods.*

Source of gasoline.	Absorption plant.[a]	Compression plant.[b]	Compression plant.[c]	Compression plant.[c]
Test No.	**1**	**2**	3	4
Gravity of gasoline. °B.'	86.2	87.4	92	75
Vapor pressure at 70° F., pounds per square inch	3½	3¾	17	3¾
Vapor pressure at 90° F., pounds per square inch	7½	9¼	20	6
Vapor pressure at 100° F., pounds per square inch	10	13¼	23	9

a Before weathering.
b After weathering and ready for shipment.
c Product from high-pressure accumulator tank.

The results of these vapor-pressure tests show a marked difference between the vapor pressure of absorption-process gasoline and that of gasoline made by the compression process. The former did not exert as much pressure before "weathering" as the latter did after weathering. It is well to call attention at this point to the reason for this difference. In a compression plant a certain pressure and temperature will be found by experience to produce the maximum yield of salable gasoline, but in obtaining this gasoline no selective pressures and temperatures can be applied that will produce solely vapors of the kind desired—that is, gasoline just right for shipping and consumption. Instead, some of the butane (gas at ordinary temperatures) is liquified and other paraffin gases, such as propane, ethane, and even methane, are dissolved in the liquid produced. Hence, the condensate evaporates rapidly when exposed to the air, largely because of the escape of the liquified and dissolved gases. These gases also exert high vapor pressures, as shown by the curves in figure 15, plotted from data obtained in experiments by the senior author.

On the other hand, gasoline made by the absorption process undergoes a selective action in the process of distilling the gasoline from the absorbed oil. The temperatures employed in the condenser are not low enough to liquify the evolved gases—butane, propane, ethane, and methane—hence, most of the condensate produced consists of those constituents that are fairly stable at ordinary temperatures.

However, as mentioned on page 43, those uncondensed vapors that escape from the still can be compressed and condensed, yielding gasoline of high vapor pressure and high rate of evaporation.

COMPARISON OF COMPRESSION METHOD AND ABSORPTION METHOD AS THE RESULT OF FOREGOING TESTS.

In summing up the results of these comparative tests of the compression and absorption methods as applied to casing-head gas, it can be stated that approximately as much gasoline can be obtained

by the absorption method at a pressure of about 25 pounds per square inch as by the compression method, and, further, a product of lower vapor pressure and lower rate of evaporation can be obtained. One important point, however, has to be considered, namely, that at many compression plants the residual gas is disposed of by forcing it into natural-gas lines at pressures higher than 25 pounds per square
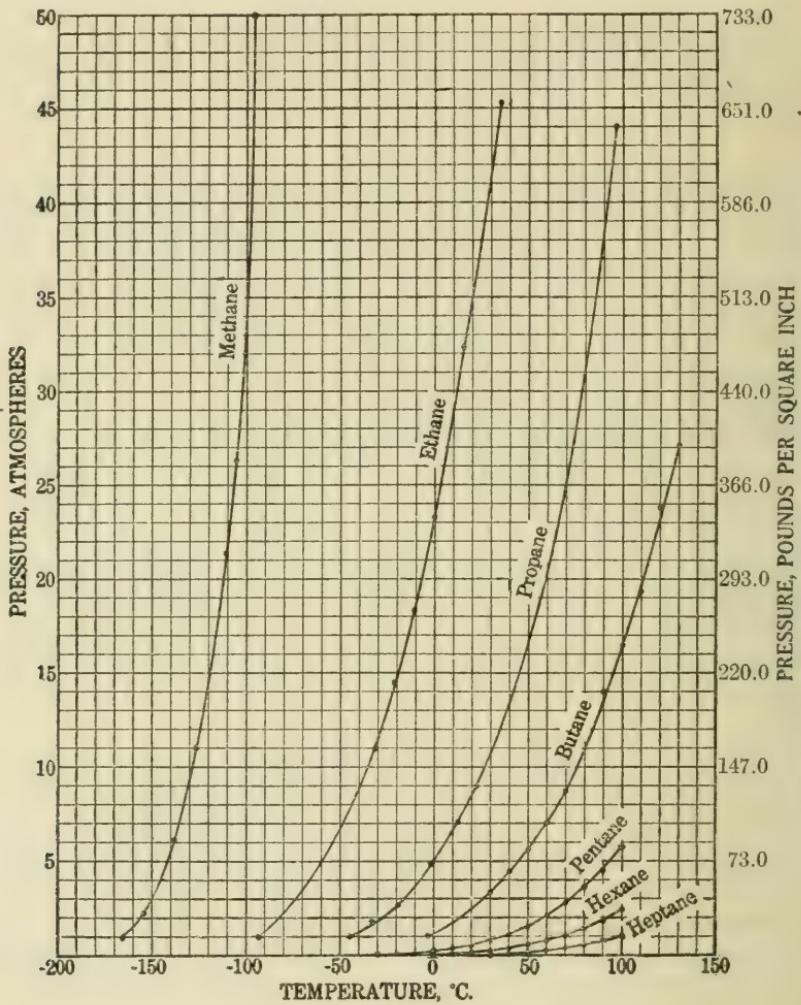
FIGURE 15.—Vapor pressure of paraffin hydrocarbons at various temperatures.

inch, being 110 pounds per square inch in the case of the compression plant herein described. Hence a compressor is needed. As the compressor with a gas engine for driving it is the most expensive part of a compressor plant and is necessary, it would be out of the question to install an absorption plant instead of the compression outfit, if the residual gas has to be pumped into a natural-gas line at high pressures. Moreover, the authors believe that the cost of operating an absorption plant is greater. The great value of the application of the absorption

process to casing-head gas lies in the fact that billions of cubic feet of this gas will be available for treatment that is too lean for treatment by compression and condensation. The significance of this statement lies in the fact that the amount of lean casing-head gas produced is much larger than the amount of rich gas—gas containing 1.5 or more gallons of gasoline per 1,000 cubic feet—that can be treated by compression and condensation.

APPLICATION OF ABSORPTION PROCESS TO GAS FROM OIL WELLS PRODUCING FROM A SAND INTO WHICH AIR HAS BEEN PUMPED UNDER PRESSURE.

A promising field for the absorption process lies in the treatment of gas from oil wells where compressed air has been forced into some of the oil wells on a lease for the purpose of increasing the production of oil from the other wells. The process consists of pumping compressed air into several wells on a lease, thus forcing more oil from that producing stratum into and out of other wells which are pumped than could otherwise be obtained. Old oil wells are treated by this method.

Messrs. Smith & Dunn, of Marietta, Ohio, have successfully installed compressor plants at such wells in southeastern Ohio and northern Pennsylvania. On one property they report an increase from $4\frac{1}{2}$ barrels to $32\frac{1}{2}$ barrels per day; on another, from 22 to 70; and on a third, from 17 to 32.

The air in passing through the oil sand picks up and carries with it some of the lighter constituents of the oil, that is—gasoline.

Of course a certain amount of the natural gas in the strata mixes with and emerges with the air and gasoline. The authors obtained information regarding the amount of gasoline carried by the mixtures as they flowed from different oil wells by collecting several samples and analyzing them. The results of three typical analyses are shown in Table 9 following.

TABLE 9.—*Analyses of mixtures of air and natural gas from oil wells.*

Constituent.	Sample 1.	Sample 2.	Sample 3.
Carbon dioxide (CO_2)..per cent..	0.20	0.70	1.00
Oxygen (O_2)..do....	18.10	15.40	16.20
Natural gas...do....	7.2	10.6	12.80
Nitrogen (N_2)...do....	74.50	73.30	70.00
Gasoline..........................pints per 1,000 cubic feet of gas..	4.6	7.3	5.9

Sample No. 1 represents about 135,000 cubic feet of gas. Sample No. 2 represents about 75,000 cubic feet of gas issuing from 12 wells. Sample No. 3 represents 25,000 cubic feet of gas from 1 well.

It will be observed that the gasoline content ranges from 4.6 to 7.3 pints per 1,000 cubic feet of gas.

ABSORPTION OF GASOLINE WITH NAPHTHA AND PETROLEUM DISTILLATE.

In the tests heretofore described the natural gas was passed through only one kind of absorbing oil and then the absorbed gasoline was separated from the oil by distillation with steam. In tests with "mineral seal oil," made with the small absorber shown in figure 2, the yield from "line L" gas by this process was about 1.2 pints of gasoline per [1],000 cubic feet of gas, and from "low field" gas, about 1.8 to 1.9 pints of gasoline.

In using the "mineral seal oil" as the absorbent, it was found that the increase in volume of the oil after natural gas had been passed through it did not correspond with the quantity of gasoline subsequently obtained from the oil by distillation. This was due to the fact that a considerable quantity of the lighter hydrocarbons was absorbed from the natural gas and increased the volume of the oil, but escaped as a gas when the oil was subjected to distillation to obtain the absorbed gasoline.

As this loss of material appeared to be considerable, an absorbent was sought that would result in these lighter hydrocarbons being saved. Therefore several tests were made in which natural gas was successively passed through three small absorbers, of the type shown in figure 2; naphtha, having a specific gravity of 55° B., was used in the first and second absorbers and "mineral seal oil" in the third absorber. The object was to absorb most of the gasoline, including the lighter hydrocarbons, with naphtha in the first two absorbers and the rest of the gasoline with "mineral seal oil."

RESULTS OF TESTS.

The results of these tests, which were made on "line L" gas are shown in Table 10 following:

TABLE 10.—*Results of extracting gasoline from natural gas by passing it through naphtha and "mineral seal oil."*

["Line L" gas was used in these tests. The gas was passed through three absorbers in series, the first and second containing naphtha and the third, "mineral seal oil."]

Item.	Test 1.			Test 2.			Test 3.		
Absorber	First.	Second.	Third.	First.	Second.	Third.	First.	Second.	Third.
Absorbent used	Naphtha.	Naphtha.	"Mineral seal oil."	Naphtha.	Naphtha.	"Mineral seal oil."	Naphtha.	Naphtha.	"Mineral seal oil."
Specific gravity of absorbent, °B	53.5	53.5	32.5	55.5	55.5	34.2	55.5	55.5	33.9
Pressure on gas, pounds per square inch	235	235	235	230	230	230	235	235	235
Rate of gas flow, cubic feet per hour	50	50	50	55	55	35.3	180	180	180
Gas used, cubic feet	200	200	200	105	105	105	200	200	200
Oil used, c.c	1,750	1,500	1,500	1,750	1,500	1,500	1,750	1,500	1,500
Oil recovered, c.c	1,950	1,610	1,565	1,925	1,560	1,510	1,850	1,555	1,600
Specific gravity of liquid recovered, °B	61.6	60.0	37.7	59.6	58.0	36.3	58.2	57.8	36.2
Temperature of liquid in absorber, °F	27	29	26	19	19	19	54	54	60
Increase in liquid in absorber, c.c	200	140	65	175	60	10	100	55	100
Quantity of sample taken for distillation, c.c			500			503			533
Amount of gasoline distilled from sample, c.c			7			2			25
Yield of gasoline, pints per 1,000 cubic feet of gas	2.114	1.480	.23	3.53	1.21	.12	1.06	.58	.77
Total yield, pints per 1,000 cubic feet of gas	3.82			4.86			2.41		

Item.	Test 4.			Test 5.			Test 6.		
Absorber	First.	Second.	Third.	First.	Second.	Third.	First.	Second.	Third.
Absorbent used	Naphtha.	Naphtha.	"Mineral seal oil."	Naphtha.	Naphtha.	"Mineral seal oil."	Naphtha.	Naphtha.	"Mineral seal oil."
Specific gravity of absorbent, °B	55.5	55.5	34.2	55.5	55.5	34.2	55.0	55.0	34.2
Pressure on gas, pounds per square inch	235	235	235	235	235	235	235	235	235
Rate of gas flow, cubic feet per hour	54	54	54	180	180	180	56	56	56
Gas used, cubic feet	217	217	217	100	100	100	202	202	202
Oil used, c.c	1,750	1,500	1,500	1,750	1,500	1,500	1,750	1,500	1,500
Oil recovered, c.c	2,040	1,600	1,560	1,810	1,525	1,560	2,020	1,595	1,530
Specific gravity of liquid recovered, °B	62.0	58.6	36.1	57.3	56.8	35.9	60.9	58.9	36.1
Temperature of liquid in absorber, °F	28	28	26	60	60	66	18	18	18
Increase in liquid in absorber, c.c	290	100	60	60	25	60	270	95	30
Quantity of sample taken for distillation, c.c			520			520			500
Amount of gasoline distilled from sample, c.c			7			16			5.6
Yield of gasoline, pints per 1,000 cubic feet of gas	2.83	.97	.21	1.27	.53	1.01	2.83	.99	.17
Total yield, pints per 1,000 cubic feet of gas	4.01			2.81			3.99		

COMMENTS ON TESTS.

It will be observed that the gasoline extracted from the natural gas that was passed through naphtha amounted to 4.86 gallons per 1,000 cubic feet of gas in the case of one test. The lowest yield was 2.41 gallons. The increase in yield over the oil absorption and distillation method varied between 300 and 500 per cent.

In test 1 the specific gravity of the naphtha was raised from 53.5° to 61.6° B. in the first absorber and to 60° B. in the second absorber. The increase in volume of the naphtha in the first absorber was 200 c. c., or 11.5 per cent, and in the second absorber, 140 c. c., or about 9.3 per cent.

The greatest increase in volume and specific gravity of the naphtha was obtained in the first absorber in test 4. The specific gravity of the naphtha was raised from 55.5° to 62° B. and the increase in volume was 290 c. c., or about 16.6 per cent. The temperature of the naphtha was 28° F.

The vapor pressure of the naphtha product in the first absorber, test 4, was 5 pounds per square inch at 100° F., and the evaporation or weathering loss was 5 per cent in 24 hours. During this weathering test the temperature of the gasoline rose from 54° to 64° F.; the temperature of the room changed from 56° to 64° F. The temperature of the naphtha had much effect on the results of the tests. The highest yield was that shown in test 2, in which the temperature of the naphtha was 19° F. This test was conducted in the open air on a cold winter day. However, even at a temperature of 60° F. as much as 3.07 pints of gasoline per 1,000 cubic feet of gas was obtained. Test 6 is instructive in that the vapor pressure of the resulting naphtha in the first and second absorbers was 14 pounds per square inch at 100° F., which exceeded that prescribed for gasoline to be shipped in tank cars.

In summing up the results of these tests, as regards the use of naphtha as an absorbent for extracting gasoline from natural gas, it may be stated that a greater yield can be obtained than by using the oil absorption and distillation process, as much as 300 per cent greater at ordinary temperatures and 400 to 500 per cent greater if temperatures as low as 18° to 19° F. are employed. A further advantage lies in the fact that the resulting naphtha with its absorbed gasoline does not have to be subjected to distillation to obtain the gasoline but can be sold as prepared.

An objection to the use of naphtha as an absorbent is that an excessively large amount of naphtha would have to be handled in large-scale operations. In using "mineral seal oil" the same oil can be used over and over again with but slight loss, whereas the naphtha is not used again and would have to be constantly renewed.

As previously stated, the greatest increase in volume of the naphtha was 16.6 per cent, in test 4. This mixture contained about six to seven times as much naphtha as gasoline, so that for each tank of gasoline extracted from the natural gas there would be needed six or seven tanks of naphtha. The naphtha should not be permitted to absorb too much gasoline, as the vapor pressure of the resulting mixture would exceed the limit (10 pounds per square inch at 100° F.) set for the transportation of gasoline in tank cars.

If an absorption gasoline plant could be located at or close to a refinery where a large supply of naphtha was available, the difficulty and trouble of transporting large quantities of naphtha into the absorption plant would be largely overcome, but in most and perhaps all cases this is not feasible.

The problem may be considered as follows: By the oil-absorption process there is obtained one-third as much gasoline as by the naphtha process. If one tank car (10,000 gallons) of this gasoline sells for, say, about 20 cents per gallon, or $2,000, three tanks will sell for $6,000, or an increase of $4,000. But in order to obtain this increase of $4,000 about seven tanks of naphtha would have to be brought to the absorption plant—that is, seven times as much naphtha would have to be handled as the gasoline extracted.

The authors have learned recently of an apparently successful use of naphtha as an absorbent for gasoline in waste gases from a compression plant treating casing-head gas. It so happens that the owner of the compression plant also has interests in a near-by refinery, so that the requisite amount of naphtha can readily be obtained. The naphtha is placed in an absorber and the waste gas from the compression plant passed through it. The naphtha is increased in volume and a salable product is obtained, so that the practice is justified. Practically the same gases are dissolved in the naphtha as accounted for the increased yield when the authors used naphtha in their tests; namely, hydrocarbon gases of lighter weight than true gasoline vapors.

SUMMARY.

The absorption method of extracting gasoline from natural gas consists in bringing the gas in contact with an oil heavier than gasoline, such as a petroleum distillate of about 34° B., to absorb the gasoline from it, and then separating the gasoline from the oil by distillation. The oil is used simply as a carrier of the gasoline from the absorption tank to the still, and may be used over and over again.

In plants using compression and condensation methods only casing-head natural gas that is comparatively rich in gasoline vapor—carrying upward of three-fourths of a gallon of gasoline per 1,000 cubic feet of gas—is treated, whereas so-called "dry" natural gas, such as

is used in cities, towns, and factories for heating, lighting, and other purposes, can be treated by the absorption process. In 1914 about 591 billion cubic feet of this kind of natural gas was used in the United States. Most of this natural gas carries gasoline to the extent of 1 to 2 pints per 1,000 cubic feet of gas, and probably 75,000,000 gallons of gasoline per year could be recovered by passing the gas through absorption plants before it is marketed, also casing-head gas that is too lean to treat by compression methods can be treated by the absorption method.

The removal of the gasoline does not reduce the heating value of the gas to an appreciable extent. In the case of natural gas from two fields that the authors of this paper experimented with, extracting the gasoline lowered the heating value only 3 per cent in one case and 2.2 per cent in the other.

A further advantage of the process, apart from the value of the gasoline recovered, lies in the fact that gasoline if left in the natural gas lines destroys the rubber in pipe couplings. The cost of replacing these rubbers and repairing broken connections, and the resulting loss of natural gas, has been a large item of expense in the operating costs of gas transportation companies.

The absorption process of extracting gasoline from natural gas becomes of greater industrial importance as the demand for gasoline increases. The method is practically identical with the process of extracting benzol and toluol (light oil) from coke-oven gases. A difference lies in the fact that coke-oven gases are treated at about atmospheric pressure, whereas much natural gas must be treated at pressures as high as 200 to 300 pounds per square inch, because it is not desirable to disturb the carrying system.

To the authors' knowledge the first large-scale installation for extracting gasoline from natural gas by the absorption process at high pressure was constructed at Hastings, W. Va., in 1913. The plant was built following experiments by G. M. Saybolt, of the operating company.

Natural gas can be tested as regards the practicability of extracting gasoline from it by the absorption process by two methods. In the laboratory method the gasoline is frozen out of the natural gas and its pressure and volume determined. In the field method, a small absorber and a gas meter are taken to the well or pipe line to be tested for natural gas, the gas is passed through the absorbent oil, and the extracted gasoline is distilled from the oil. The results duplicate on a small scale those in a commercial plant.

All natural gas, except that which contains methane as the only combustible gas, contains gasoline vapor. However, in gas from some wells the gasoline content may be very small. This is sometimes due to the fact that the gas may be under very high pressure and

the gasoline vapors, because of their greater density at this high pressure, are not produced in quantity until the pressure is relieved. But even high-pressure wells represent potential sources of gasoline supply in that the gas will carry commercial quantities of gasoline vapor as the pressure declines.

Natural gas from two different fields that the authors tested contained 1 pint and 1.5 pints, respectively, of gasoline per 1,000 cubic feet. About 50,000,000 cubic feet of natural gas per day was available for treatment.

The oils the authors used in the experiments to absorb the gasoline were petroleum distillates which had a specific gravity of about 35° B., and started to boil at about 400° to 482° F. It is necessary that the boiling point of the oil used be much higher than the boiling point of the gasoline to make the extraction of the latter by distillation easy.

Tests were made with a plant of fairly large proportions, capable of handling 15,000 to 30,000 cubic feet of gas per hour. The principal features of the plant consisted of an absorber where the natural gas and absorbent oil were brought in contact with each other, a heat exchanger where the oil with its absorbed gasoline was heated before going to the still, a steam still where the gasoline was extracted from the oil, a cooler where the hot oil from the still was cooled before receiving another charge of gasoline, pumps, and a weathering tank.

Several different types of absorbers were tried. The one giving the best results consisted of a tower filled with pebbles, in which the oil flowed downward and the gas upward.

An increase in the temperature of the oil in the absorber from about 75° F. to about 85° F. lowered the gasoline yield about 0.3 pint per 1,000 cubic feet of gas. An increase in the pressure of the gas from atmospheric pressure to 110 pounds per square inch increased the yield from 0.7 pint to about 2 pints of gasoline per 1,000 cubic feet of gas.

The specific gravity of the gasoline obtained varied between 77° and 85° B. The boiling point ranged from 80° to 300° F. The evaporation loss was about 11 per cent in 24 hours as compared to 2.4 per cent from a "straight" refinery gasoline having a gravity of 60.4° B. The vapor pressure of the gasoline ranged from 1 pound at 70° F. to about 5 pounds at 100° F. This is important because it shows that the gasoline can be safely shipped in tank cars.

The absorption process can be profitably operated at low pressures.

As good results can be obtained from casing-head gas with the absorption process as with the compression process. However, where the residual gas from the plant has to be forced into a pipe line at high pressure there is no advantage to installing an absorption plant, because a compressor would be needed anyhow.

A promising field for the absorption process lies in the treatment of gas from oil wells producing from a sand into which air has been forced under pressure to increase the oil production. This gas, as it flows from the wells, can be treated by the absorption process and the gasoline it contains extracted.

The amount of power required for the operation of an absorption plant will vary from 0.018 to 1.443 boiler horsepower per 1,000 cubic feet of gas treated per hour for gas containing 0.0625 to 5 gallons of gasoline per 1,000 cubic feet, and the amount of water from 1.46 to 116.8 gallons per 1,000 cubic feet of gas.

The rate of flow of the absorbing oil will vary from about 6 to 60 gallons per 1,000 feet of gas treated per 24 hours, for gas that contains from 1 pint to 2.5 gallons of gasoline per 1,000 cubic feet.

A successful use of naphtha as an absorbent for gasoline lies in the absorption in the naphtha of waste gases from compression plants treating casing-head gasoline.

Some tests were made in which natural gas was simply passed into naphtha with a gravity of about 55° B. When the naphtha had absorbed all the gasoline that was desired it was removed and fresh naphtha substituted. The yield of gasoline was 300 to 500 per cent greater than that by the oil absorption and distillation process. In some tests the naphtha besides being increased in volume owing to the absorbed gasoline, was raised in specific gravity to 60° or 62° B. An objection to the process lies in the fact that a large amount of naphtha has to be handled—at least seven tanks of naphtha for each tank of gasoline obtained. If the naphtha is permitted to absorb too much gasoline its vapor pressure is raised too high for safe transportation.

There are possibilities in the application of the absorption method to casing-head natural gas, much of which is too lean to be treated by compression and condensation methods.

ACKNOWLEDGMENTS.

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